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VOLUME 10, NUMBER 3 • MARCH, 1954

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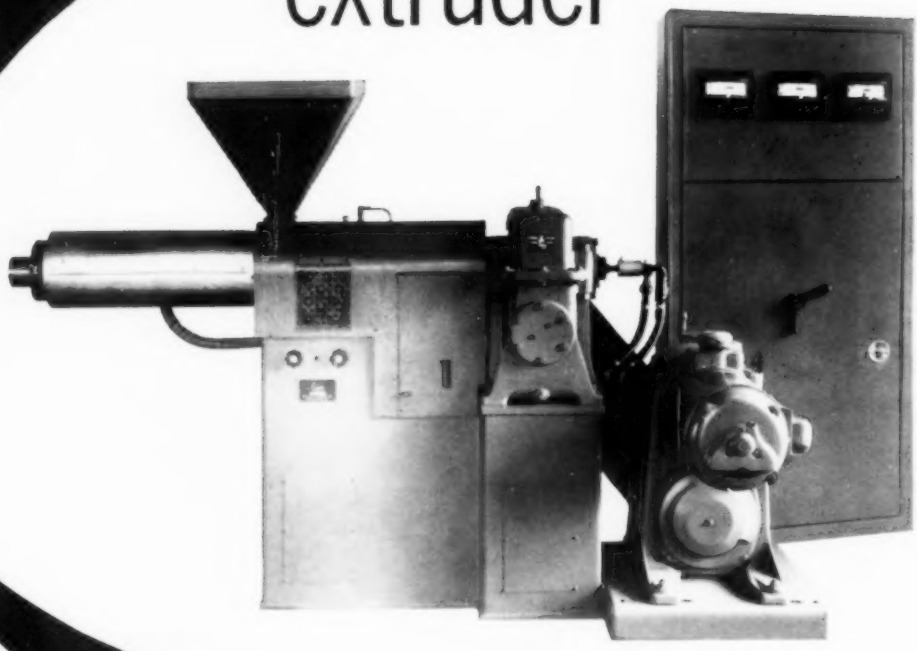
National officers of SPE for 1954 are, (left to right) Frank Reinhart, Secretary; Don Hoffman, Vice-president; John LaBelle, President; John Mallory, Treasurer.

Egan

extruder



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JOURNAL

Vol. 10 March, 1954 No. 3

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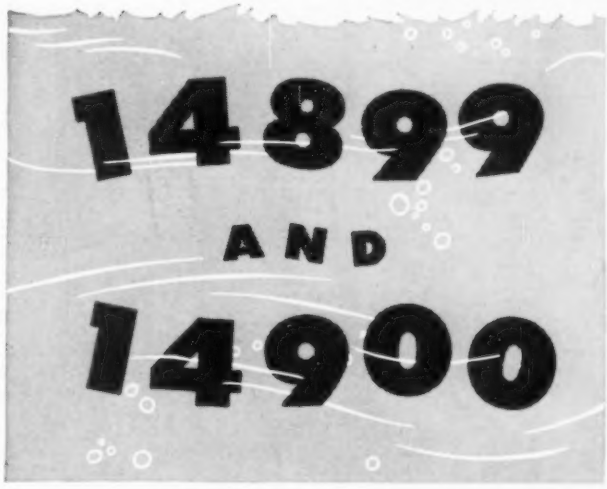
give top performance "in the swim"

HOT OR COLD



THESE TWO Durez phenolics offer you a profitable field of application for service in the presence of moisture and mild chemicals such as soaps and detergent solutions. Their range of use is suggested by their acceptance as standard materials for . . .

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Book Reviews

QUANTITATIVE ORGANIC ANALYSIS VIA FUNCTIONAL GROUPS by S. Siggia. (2nd ed.) Published by John Wiley and Sons, Inc., 440 Fourth Ave., New York, New York. 227 pages; Five dollars.

Quoting from the preface; "It is the purpose of this book to give a series of working methods for determining organic compounds by the functional groups on the molecule. Determination of an organic compound by functional group analysis is much to be preferred to determination by analysis for the elements.— This book was written with a view to its use by laboratory analysts— It eliminates the need for searching through the literature and for weeding out and testing procedures that show promise."

This introduction is a fair statement of the scope of the book, and it should be noted that these are practical procedures, given in detail, for the determination of all the common organic functional groups and many of the less common.

While the book is written for work with simple molecules rather than high polymers, your reviewer believes that this book will be very useful to high polymer chemists in suggesting methods that could be applied to end group analysis, or substitution group analysis, in plastics materials.

This book is authoritative and very well and lucidly written. It is a must for any chemist confronted with the problem of organic analysis.

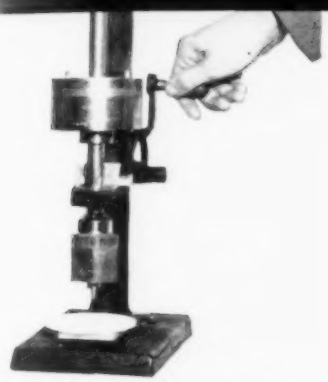
Industry Notes

Static Eliminator

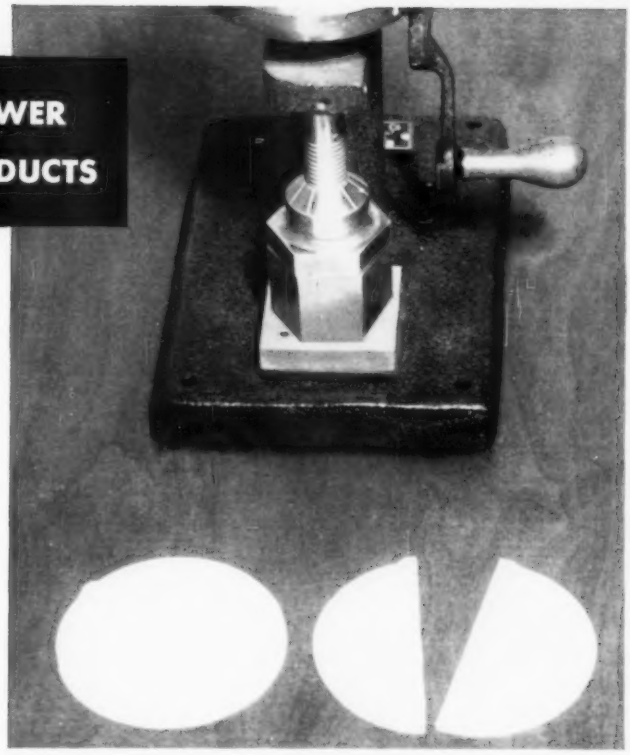
ANSTAC 2-M, believed to be the most effective and long lasting antistatic and cleaning agent available today, is now being used in many new industrial applications. One of the most important uses for this product is to eliminate static charges on aircraft canopies and windows. These plastic surfaces tend to accumulate tremendous static charges which in turn are the main cause of dust and dirt attraction. Dust and dirt are the primary causes of scratches, and can be practically eliminated by preventing electrical build-up. The surface is simply rubbed with a cloth which has been dampened in ANSTAC 2-M. The surface is cleaned and the static charge is completely eliminated for long periods of time.

ANSTAC 2-M does not depend on moisture for its effectiveness. Therefore, the treated article does not have a film of moisture on its surface to which dust and dirt will adhere. It is non-inflammable and can be stored indefinitely. Write Chemical Development Corp., Danvers, Mass.

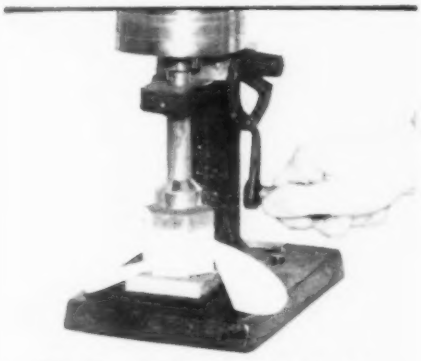
PUT SELLING POWER INTO YOUR PRODUCTS



"Needle-Penetration" Toughness Tester consists of weighted needle and hand crank. Needle shown in raised position before being tripped to fall on test sample.



Comparison of discs made of Lustrex Hi-Test 88 (left) and general purpose styrene after needle penetration tests.



Descending needle shatters test disc made of general purpose styrene.

Falling needle *punctures* test disc of Lustrex Hi-Test 88 indicating the strong shock resistance, and excellent flexibility and elongation of this material.

Punishing impact test points way to product quality . . . with HI-TEST 88 LUSTREX Styrene Plastic

Consider what this dramatic demonstration of Lustrex Hi-Test 88 styrene can mean for your products. Now, at a time when your customers—manufacturers, retailers and consumers—are becoming more and more insistent on improved product performance, you can provide a competitive advantage with a stronger, tougher, more durable material.

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Lustrex Hi-Test 88 has good appearance, good color stability, and excellent moldability. It has outstanding vacuum forming characteristics. Can be extruded or molded. Because it orients less (and thus has less variation in internal stress), it is highly recommended where lacquering is done.

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The English Mica Co. . . . of 79 Prospect Street, Stamford, Connecticut . . . has the finer grades available from 160 mesh to a theoretical 3,000 mesh.

Write The English Mica Co. . . . of 79 Prospect Street, Stamford, Connecticut for information on the Finer Ground Micas and U.S. Mica Co., Inc., Jordan & Van Dyke Streets, East Rutherford, N.J. on the coarser Ground Micas.

Your National Office

The name of the Society of Plastics Engineers can be literally heard around the world. Do you know, we have active members in Central and South America, Great Britain, Sweden, Holland, Denmark, Switzerland, Spain, Germany, Burma, and India. In addition, there are subscribers to the JOURNAL in many other countries.

The correspondence received here in the National Office is frequently in French, German, Italian, Portugese, or Spanish. **Christmas greetings were also received in Japanese.**

There is interest even in organizing a section of the Society in the Far East!

This year's theme "Plastics International" calls to mind these international relations of the Society. It sparked in me also a curiosity about organizations comparable to ours that might exist in other countries.

At the Conference—it was really a great success, incidentally—I took advantage of the opportunity to obtain some firsthand views on the organizational division of interests in the plastics industry in the United Kingdom. The similarity to ours is very striking.

The British Plastics Federation, which represents trade interests, might be likened to the Society of the Plastics Industry in this country. The Plastics Institute, which represents the professional side of the industry, is the British counterpart to the Society of Plastics Engineers.

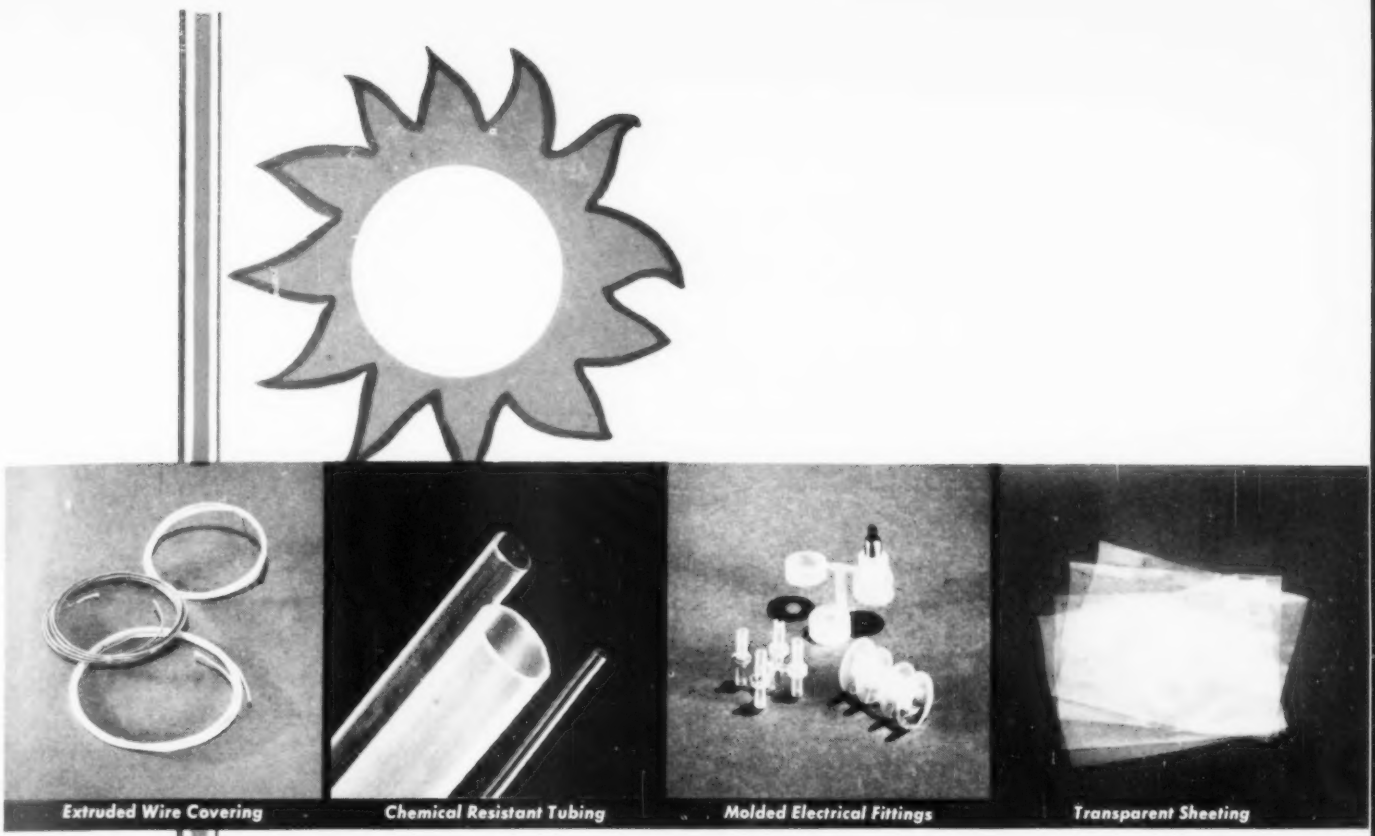
And the interests the Plastics Institute and the Society of Plastics Engineers share in common are many. In outline—the Plastics Institute's object, for instance, is to promote the cause of the plastics industry in Great Britain, etc.; the Institute has ten local sections; its membership classifications are Fellow, Associates, Ordinary Members, and Junior Members; its committees include an Education and Honorary Technical Advisers Committee; and they publish a technical journal called "Transactions."

The Secretary of the Plastics Institute has recently proposed an exchange of news and technical information between our two organizations. Details about the Institute can be obtained by writing to the Institute at The Adelphi, Street, London W. C. 2.

I know many of our members go abroad frequently. The Secretary of the Plastics Institute extends an invitation for you to visit him at the Institute's offices. And **no matter where you are traveling your National Office will be very happy to put you in contact with people who know your Society and who share your interests in plastics.**

P. L. Underwood

Executive Secretary



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Products made from BAKELITE Fluorothenes can be used effectively between minus 195 deg. C. and 220 deg. C. Successful experiments have shown that these materials are practicable for high-temperature wire insulation, valve seats, gaskets, and insulation for printed circuits.

They have excellent chemical resistance. For example, fluorothene is used for containers and piping to carry corrosive chemicals such as fuming nitric acid. An outstanding electrical property, especially at elevated temperatures, is volume resistivity which is so high that it can be measured only by extremely sensitive instruments.

BAKELITE Fluorothenes are rigid thermoplastic polymers—so hard that hammer blows on a solid piece hardly leave a mark. Long periods of submersion reveal no sign of moisture absorption. Tests on various thicknesses of wire insulated with fluorothenes showed that they will not support combustion.

These characteristics are already generating interest among industries connected with chemical processing, electric power, packaging, medical supplies, radio and television. Detailed technical information is available from Bakelite Company in a free booklet describing the forms, properties, and fabrication of BAKELITE Fluorothenes. To get your copy, write Dept. TH-43.

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Membership Competition

Goal: Membership of 5000 by October 1

SECTION

	MEMBERSHIP Oct. 1, 1953	NEW APPLICANTS Nov.	Dec.	Jan.	Feb.	Mar.
Baltimore-Washington	49	1	0*	0*	1	1
Buffalo	65	3	1	1	1	3
Central Ohio	33	0*	1	0*	0	
Chicago	315	7	10	4	6	9
Cleveland-Akron	148	10	4	3	6	10
Connecticut	86	1	5	1	1	9
Detroit	173	6	0	7	4	10
Eastern New England	132	1	1	3	4	7
Golden Gate	32	3	2	0	3	2
Miami Valley	102	1	1	0	0	4
Newark	321	9	17	5	6	12
New York	248	1	17	4	12	14
Northern Indiana	21	1	0*	0*	2	14
Northwest Pennsylvania	75	4	2	2	0	11
Ontario	43	3	14	6	31	12
Philadelphia	174	6	0	3	12	12
Pittsburgh	6	3	4	1	0	13
Quebec	25	5	2	9	8	9
Rhode Island & S. E. Mass.	68	2	2	0	3	3
Rochester	65	4	3	3	2	18
St. Louis	71	0	4	9	1	2
Southeastern Ohio	36	0*	4	0*	0	1
Southern California	96	6	7	2	3	10
South Texas	32	5	0	1	1	2
Toledo	59	0*	0*	0*	1	4
Upper Midwest	54	4	1	0	3	1
Western New England	135	7	8	0	7	1
Non-Section	37	0	3	9	5	4
TOTALS	2704	93	113	73	123	1

Industry Notes

Cavitron Appoints Sheffield

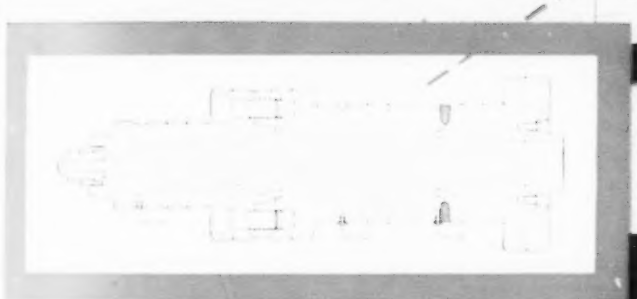
The Sheffield Corporation of Dayton, Ohio, will henceforth design, manufacture and market Cavitron machine tools, according to a joint announcement by the Cavitron Corporation, Long Island City, New York, and Sheffield.

The Cavitron machine tool is a remarkable device utilizing an ultrasonic vibrating head and an inexpensive tool (such as soft steel) for the precision cutting of hard and brittle materials, either ferrous or non-ferrous, such as the carbides, germanium, hardened tool steels, sintered aluminum oxide, quartz, industrial crystals, ferrites, various types of glass, ceramics, sapphire, and other materials difficult to machine. It may be used for extremely precise external or internal machining similar to cutting, drilling and grinding of holes, cavities, slots and recesses of any shape, as well as precision forming of external profiles. Extremely fine surface finish is obtained, and there is no local heating of the work surface or chemical or physical change in the work piece. Write Box 893, Dayton 1, Ohio.

IT'S RED HOT

H-P-M's NEW HEATING CHAMBER

INCREASES PLASTICIZING CAPACITY 100%



NEW HEATING CHAMBER DESIGN now standard on all H-P-M 9, 16, 32 and 60 oz. plastics injection molding machines.

40% SAVINGS IN CYCLE—Example: A 7½ oz. shot, formerly molded on a 12 oz. competitive machine in 37 seconds, is now molded in H-P-M's new 9 oz. in just 23 seconds . . . a 14 seconds saving per shot.

HOW ABOUT WALL TILE? Example: H-P-M's 16 oz. with new heater is producing tile (4½"x4½"x.065" thick) in an 8-cavity mold on an 18-second floor to floor cycle!

QUICK COLOR CHANGE—Example: When molding cellulose acetate, the new H-P-M 9 oz. requires only 7 lbs. material to change from flesh color to white!

EASIER MOLD FILLING—Example: In testing new molds, a 48-cavity doll arm mold was filled in first shot with H-P-M's new 9 oz.

- 3-zone heat control with concentration of high wattage heaters at chamber entrance.
- Heat is applied directly to spreader, eliminating air gaps and resultant heat loss.
- Narrow, high-temperature heating bands, with stainless steel clamps, provide excellent contact with chamber.
- High efficiency of new chamber lowers heat requirements approximately 100° F. and injection pressures reduced as much as 3000 P.S.I. on the material.
- New chamber is ideally suited for all modern thermoplastic materials — including flexible vinyl.
- Chamber is easily dismantled for cleaning.
- Improved terminal block — mounted directly on chamber —eliminates need for long wire leads.
- H-P-M's threadless, quick-change nozzle tip can't break off in the chamber!

WRITE FOR FULL DETAILS TODAY!

HPM

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PRESSES FOR EVERY PRESSURE PROCESSING APPLICATION

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Traps • Strainers • Temperature Controls

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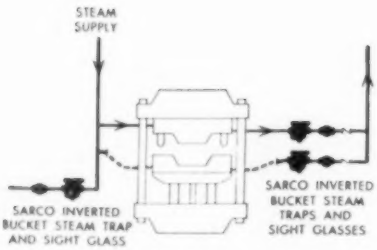
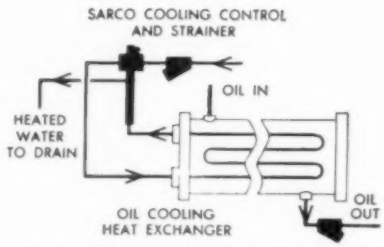
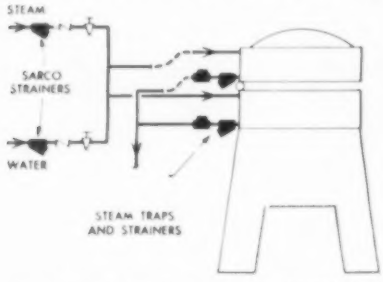


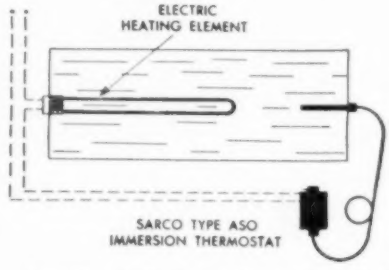
Compression molding press fitted with Sarco Inverted Bucket Steam Traps, the blast discharge of which scours the heating surface of the platens.



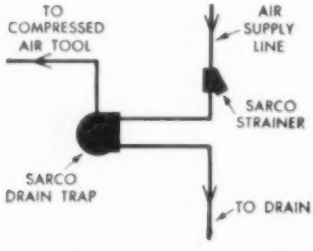
Heat exchanger cools hydraulic oil of plastics molding machines. Temperature of the cooling water is regulated by the Sarco Cooling Control.



Sarco steam traps on a steam-heated and water-cooled molding press.



Annealing bath temperature controlled by Sarco type ASO electric immersion thermostat.



Sarco Type F.A. trap draining small line to compressed air tool.

SEND FOR THESE SARCO BULLETINS

Inverted Bucket Traps	360
Compressed Air Drain Traps	520
Cooling Controls	700
Type ASO Electric Thermostats	1000
Pipe Line Strainers	1200 and 1225

Need help with your process heating equipment? Sarco can show you how to improve the output of your steam heated machines — cut your steam costs. Our years of specialized experience in the manufacture and application of traps, strainers and temperature controls are at your service.

Send us a sketch of your hook-up problem, we'll check it and send you our recommendations without cost or obligation.

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Industry Notes

PRECISION PIN DRIVING MACHINE IS 300% FASTER THAN HAND METHODS

The new, improved Milliken Precision Nailer quickly and precisely drives nails, pins, rivets into wood, plastic, some metals and other materials.

Parts to be joined are held on the work table under the nail jaw. A press of the foot treadle automatically drives pin through the parts to be joined at the exact spot desired. The machine does not strike a blow; rather it carries a sustained driving action off the flywheel. Consequently, various "difficult" materials such as plastics, masonite, hard woods and thin strips of metal can be nailed with little danger of splitting or cracking.

For further information about the new Milliken Nailer, write to the manufacturer, Mr. N. F. Hoard, President, Press Wireless Laboratories, Inc., Dept. N, 25 Prospect Place, West Newton 65, Mass.

NEW 12" ADJUSTO TEMPLATE IS ANNOUNCED

A New 12" model AJUSTO Profile Template is now offered to industry in addition to the 6" AJUSTO by Toolcraft Mfg. Co., P. O. Box 567, East Chicago, Ind.

The 12" uses brass strips .010" thickness. Both a male and a female profile are obtained in a matter of seconds of objects 12" long and 4" depth of contour. Additional adjustment and locking force has been incorporated by using a right and left hand threaded member to apply pressure on both ends at once.

The new 12" AJUSTO in wood case is priced at $69.50.

ALLIED PRODUCTS ENGINEERING CHANGES OFFICE LOCATION

Allied Products Engineering Corporation announces the removal of its offices from 4707 Crenshaw Blvd., Los Angeles, California, to 1225 East Grand Avenue, E. Segundo, California.

This company distributes fiberglass resins, Styrofoam, and various accessories to these products.

Allied Products Engineering Corporation is the Western Manufacturers representative for the Strux Corporation, Dexolium Corporation, Modigliana Glass Fibers, Inc., and the Schori Division.

In its new and larger plant, in addition to distribution, this company will undertake the lamination and shaping of Strux and Styrofoam for the ultimate users of these compound materials.

1100 Attend SPE's Tenth Conference "Plastics International" at Toronto

More than 1100 persons attended the SPE's Tenth Annual Technical Conference in Toronto, January 27 through 29, "Plastics International" was a success in every respect.

The turnout at the technical sessions was impressive, to say the least, with 500 to 600 attending many of the papers.

Every credit should be given the hard working Canadian Conference Committee, and to the Royal York Hotel, for the smooth way in which every function went off.

The Annual Banquet, attended by over 600, saw the presentation to the membership of the new National Officers for 1954. John LaBelle of Foster Grant Co., Leominster, Massachusetts, is President. Mr. LaBelle, incidentally, was general chairman of the 1953 Technical Conference. Vice-President is Don Hoffman, of Evans-Winter-Hebb Co., of Detroit. Frank Reinhart, Chief of Organic Plastics section of the National Bureau of Standards, was elected Secretary. John Mallory, Parker Stamp Works, was elected Treasurer.

Mrs. Bess Day, executive-secretary of SPE from January of 1948 to July 1953, was presented with an Honorary Membership in SPE, at the banquet ceremonies. She is the third person in the SPE to be so honored. She was presented with four place settings of Rosepoint sterling silver by the members of the National Council in recognition of her contributions to the SPE.

Joe Healey, National Membership Chairman, set up business opposite the registration table and is responsible for 77 new members!

The new membership lapel-button was on view for the first time, being worn by Lee Swift of the Chicago Section. The pin is a real beauty and one that we can well be proud to wear. Just when they will be available is not certain, but two or three months — probably minimum.

The convention identification lapel buttons were molded by Brantford Molded Plastics, Ltd., the material by Dow of Canada, and Monsanto Canada. The molds have been given to the SPE for one dollar, by the Parker Stamp Works.

No one at the Conference needed to wonder where the 1955 Conference will be held. Prominently displayed in the lobby, and at the banquet, was a sign "Set Sail for Atlantic City," and similar signs were apparent on many lapels. The '55 Conference is set for Chalfont Haddon Hall, Atlantic City, and plans are made for an attendance in excess of 1600.

SCENES AT THE SPE ANNUAL BANQUET

Head table at SPE's Annual Banquet, January 28. Left to right; Frank Reinhart, Stanley Bindman, Jim Underwood, John LaBelle, Walter Oelman, Gordon Beatty, Banquet speaker Emmett O'Grady and (hidden by flowers) Mrs. O'Grady, Bess Day and John Mallory. Out of sight to the right were Frank Carmen, Jesse Day and Graham Rae.

View of the banquet hall.

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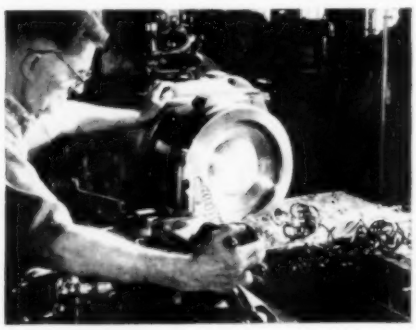

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VINYL PASTE RESINS . . .

today and tomorrow

W. D. Todd
B. F. Goodrich Chemical Co.

MOST OF US WHO WORK in plastics have a fair notion of the nature of vinyl dispersions or pastes. But in order that we can all start from the same point, it seems desirable to summarize briefly a few of the principles of vinyl paste technology. When this is done, we can proceed to some of the present uses and some of the newer applications where pastes may be expected to play a role of increasing importance.

Vinyl pastes, as the term is generally applied, are dispersions of polyvinyl chloride or vinyl copolymers in non-aqueous liquids. They had their origin in Germany some twenty years ago. At the present time, there are five well known manufacturers of paste resin in the United States. Since production figures are top secret, we can only estimate. However, on the basis of a survey made recently by the writer, it was concluded that the total production of paste resins in the United States in 1952 was around 40 million pounds and that this value constituted a four-fold growth over 1947. If we assume that the resin represented roughly one-half of the total of the dispersions involved, we end up with a figure of about 80 million pounds, which indicates a tremendous growth trend.

The structure of vinyl pastes is that the solid phase—a finely divided high molecular weight polymer—has limited solubility in the liquid or dispersing phase at room temperature. After the dispersion is applied in any desired manner, it is heated to bring about mutual solvation of the resin and the plasticizer, thus converting the dispersion into a cohesive solid.

Vinyl pastes vary from thin liquids to putty-like solids, and within this wide consistency range, can be sprayed, printed, brushed, cast, spread, slushed or extruded. There are also advantages over other well-known methods of processing vinyls. For instance, solutions of these same polymers require expensive solvents and results in low solids content compositions. Vinyl latex is subject to freezing, tends to rust metal equipment and shrinks fibrous materials. Hot processing requires considerable power and heavy machinery and subjects the resin to long heat history in the process.

Definitions of Plastisol

The resins which are designed for vinyl dispersions are of small ultimate particle size (one to two microns) and are usually furnished in one of two forms, differing in their average state of aggregation. These are known as the "stir-in" or the "grinding type" resins, the names indicating the degree of attrition necessary to prepare a smooth dispersion. The types of vinyl pastes which are derived from these resins may be divided into four main categories as follows:

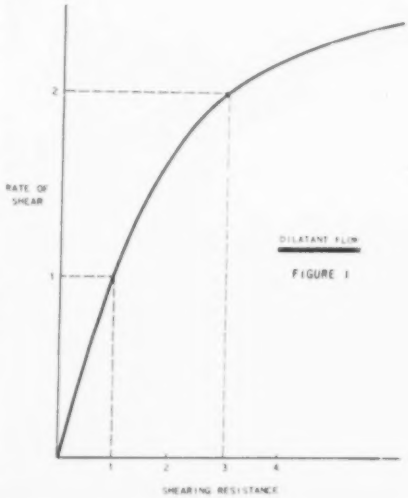
(1) Plastisols—in which the liquid phase consists entirely of a plasticizer, such as dioctyl phthalate.[1] The common levels of plasticizer content are from 50 to 100 parts, based on 100 parts by weight of the resin. At the lower levels, a crowded system results as can be seen in Table I. While there is adequate plasticizer for the closest packed system—the rhombohedral — there is insufficient for the most open-spaced — the cubic. But this is not the whole picture because of the slight solvating action of the plasticizer on the resin at room temperature. As a result, some plasticizer is immobilized on the surface of the resin particles, thus reducing the plasticizer available for fluidity and simulating a more crowded system. The net effect is to produce dilatant flow properties which are illustrated in Figure 1. It can be seen that doubling the rate of shear more than doubles the shearing resistance. This then, is a characteristic of most plastisols.

TABLE I — Volume Relationship in a Simple Plastisol

	Weight	Specific Gravity	Volume	% Volume
Resin	100	1.4	71	59
Plasticizer	50	1.0	50	41

Assuming spheres of equal size,

Packing	Volume of Voids[1a]
Rhombohedral	18%
Cubic	48%



DILATANT FLOW

FIGURE 1

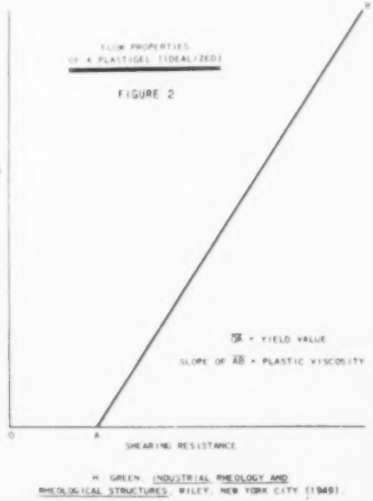


FIGURE 2

H. GREEN, INDUSTRIAL RHEOLOGY AND RHEOLOGICAL STRUCTURES, WILEY, NEW YORK CITY (1949).

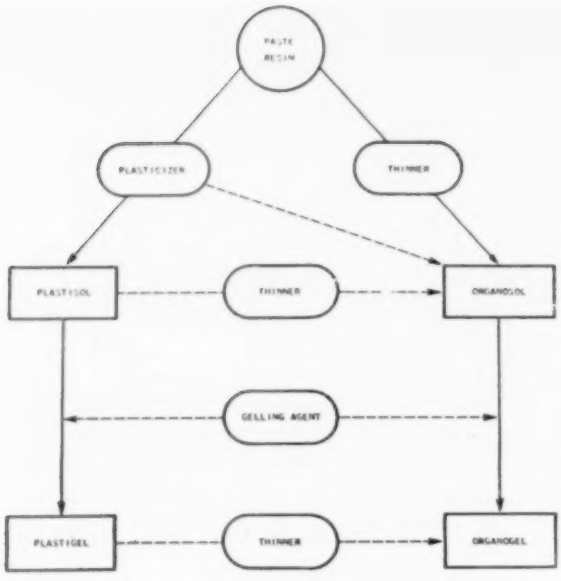


Figure 3. Types of Vinyl Dispersions

(2) Plastigels — plastisols with gel-like flow properties; having an effective yield value.[1] Note that this definition does **not** restrict plastigels to high consistency putty-like materials. The flow properties of plastigels are represented in Figure 2. Here we can see that if the system is at rest, a certain resistance has to be overcome in order to initiate flow. These pastes behave so differently from ordinary plastisols that they justify a separate grouping. For the moment, let us pass by a discussion of the attainment and significance of yield values.

(3) Organosols — in which the liquid phase contains volatile liquids-thinners.[1] The simplest form of an organosol is one derived from a plastisol by the addition of a thinner, the usual purpose being to reduce viscosity. A more complicated type is known as a "ground organosol" where the thinner plays an important part in the formulation and preparation. The variation in viscosity of a series of organosols all having the same total solids content but varying in dispersant-diluent balance, shows a minimum viscosity point which is characteristic of all ground organosols and is usually sharper the lower the plasticizer content. The higher viscosity organosols with more dispersant are oversolvated and tend toward gel structure while those with more diluent have insufficient solvation for optimum viscosity and tend towards flocculation. The terminology and the interpretation of this phenomena is that contributed by Powell and his coworkers who pioneered in this field.

It should be pointed out that organosols, like plastisols, also have non-Newtonian flow properties but, when properly formulated, they are not as pronounced since the liquid-solid ratio is generally higher.

(4) Organogels — organosols with gel-like flow properties; having an effective yield value. This term is suggested to cover that type of paste which corresponds to a plastigel containing a thinner.

The relationship of the four main categories of pastes may be summarized by reference to Figure 3. A very broad grouping of the general characteristics of vinyl pastes is shown in Table II. As indicated, the ranges given for the various properties are those most normally encountered.

The mixing of vinyl pastes is best accomplished under conditions of high shearing stress rather than high speed and the temperature of the mix should be controlled — if possible below 85°F—since these systems are temperature sensitive. Whenever the optimum transparency is required in a cast or dipped film of a high solids paste, it is usually deaerated by subjecting it to a vacuum. This operation can be done batch-wise or continuously. For a great many uses where pastes are pigmented or subsequently embossed, deaeration is unnecessary. The normal fusion temperature for pastes is 350°F.

There are two basic requirements in the formulation of any vinyl paste: It must have satisfactory flow properties for the intended process and it must have the desired end properties after fusion. Both are affected by the kind of ingredients, their proportions and the method of preparation.[2] Without going into detail, it can be stated that the plasticizers and stabilizers are generally the same materials used in other vinyl compounding and that combinations are frequently employed to take advantage of the varying properties of each. A high degree of fluidity is desirable in plasticizers since, for example, the initial viscosity of a plastisol is directly proportional to the plasticizer viscosity. With two exceptions, solid ingredients are preferably added as preground dispersions in a portion of the fluid medium. In the case of a ground organosol, the common procedure is to charge all of the raw materials directly into the ball mill. And, in the case of stir-in plastisols, it is often possible to add the filler directly to the mix in the dry form.

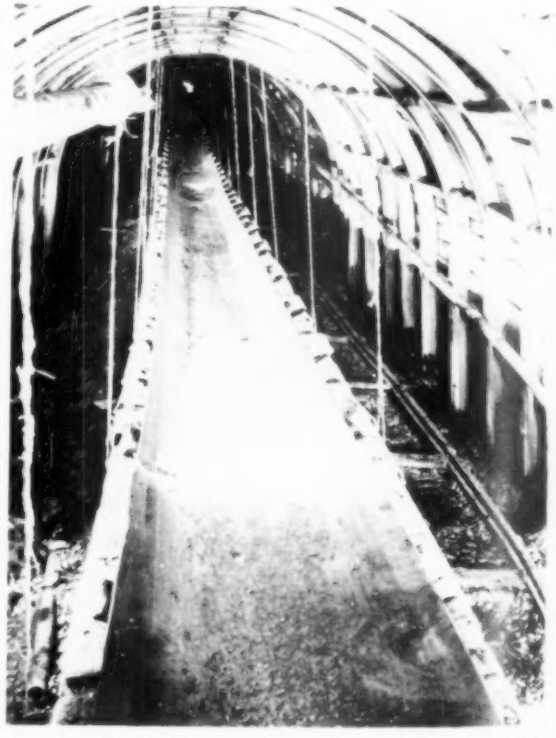


Figure 4. Plastisol Coated Mine Conveyor Belt 30" Wide (Installed August 1948, still in good condition after nearly five year's use. Courtesy British Belting and Asbestos Ltd. and British Geon Ltd.)

TABLE II—Characteristics of Vinyl Pastes

	(1) Plastisol		(2) Plastigel	(3) Organosol		(4) Organogel
	Stir-in	Ground		Stir-in	Ground	
Preparation	Change can or Planetary Mixer	Three-roll or Ball Mill	(Any in #1)	Change can or Planetary Mixer	Ball or Three-roll Mill	(Any in #3)
Usual plasticizer level, parts per 100 parts resin	50-up	50-up	80-up	30-up	0-up	50-up
Usual total solids, percent	100	100	100	70-up to 100	50-70	85-up to 100
Usual flow characteristics	Dilatant	Dilatant	Presence of yield value (plastic)	Variable to near-Newtonian	Variable to near-Newtonian	Presence of yield value (plastic)
Common thickness range as applied, inches	0.005 to 0.25	0.005 to 0.25	0.01 to 0.5	0.002-0.02	0.001-0.01	0.002-0.02
Hardness range, Duro A	30-100	30-100	50-80	70-100	70-100	30-100

Let us now turn our attention to applications. Up to the present time, the greatest consumption of vinyl pastes has been in spread coating. A typical illustration is the coating of fabric for upholstery. The early materials used were drying oils and rubber solutions. These were replaced by pyroxylin coatings which were, in turn, replaced by vinyl, in one form or another. We must say, "in one form or another," so as not to overlook calendering. Each method may be used for the production of fabric coating and of course, unsupported films. Paste spreading equipment, however is much cheaper initially and from an operating standpoint. Moreover, the paste film is strain-free.

A coating line for the spreading of plastisols and organosols consists of a coating head, a fusion oven and auxiliary equipment for the handling of the web. The coating head may be a knife or a roll coater and, if desired, embossing may be done with cooled rolls upon leaving the oven. The coating speeds are governed by the time required to complete paste fusion. The usual coating speeds are 15 to 30 yards per minute, a few installations exceeding 50 yards per minute. For coating paper, 200 yards per minute is not uncommon. Cast film may be decorated by printing the design on the carrier so that when the fused film is stripped from the carrier, the design comes with it.

Two problems arise occasionally in the spread coating of fabrics. These are excessive penetration and what is known as "spitting." There are times when deep penetration is desirable but if the utmost of flexibility or "hand" is required, there should be only enough penetration for adhesion. Spitting arises in the case of highly dilatant pastes which are being coated at high speeds or in thin gauge. Pressures developed are sufficient to force excess compound under the knife forming an uneven coating or else collecting on the back side of the blade and dropping off in blobs. Aside from other corrective measures, both of these difficulties can be attacked from a compounding standpoint in the same fashion because they are somewhat related. The remedy lies in the reduction of dilatancy and in the cultivation of a yield value. The replacement of part of the resin by another paste resin of different particle size is effective. If the substituted resin is larger in particle size, viscosity is reduced; if smaller, viscosity is increased; while in both cases, dilatancy is reduced. Plasticizers which are known to confer low temperature flexibility almost without exception provide lower viscosity pastes than the standard plasticizer, dioctyl phthalate. This is of value in reducing dilatancy. Also, tricresyl phosphate should be avoided if dilatancy is to be kept to a minimum. The addition of high oil absorption fillers along with an equivalent quantity of plasticizer based on oil absorption values will build a yield value. Certain gelling agents have the same effect. Finally, the addition of a diluent-type thinner will tend to produce yield.

Fabric coating with pastes is a well established industry. Less established, but growing steadily are other spread coated products such as flooring, wall covering, protective clothing, rug backing and conveyor belting. In England, linseed oil is rapidly being ousted from the oil-skin or "foul weather" industry because of the demand by the Admiralty that such materials possess not only a wide temperature flexibility but also that they be fully non-flammable. Other English uses which are growing are paste coated asbestos cloth for flexible railway coach connecting walls and paste coated tarpaulins for open trucks and railroad freight cars. A major development in England is the current switch-over from rubber to paste coated belts in mine conveyors (See figure 4). The extent of this business can be judged by the fact that 14 million pounds are spent annually on the replacement of underground belts.

In one of the tests required by the National Coal Board, a sample belt is held stationary under load around a driven drum. The belt must not smolder or catch fire as long at it remains intact. Neoprene stock is said to wear away by dusting until the steel drum comes in contact with the fabric, often igniting it. While the belt will not transmit fire because of the Neoprene covering, the damage is already done because in a mine everything is covered with coal dust. In the case of a paste coated belt, the thermo-

(please turn to page 39)

The Mechanical Properties of POLYETHYLENE

Robert H. Carey
Bakelite Company
A Division of Union Carbide and Carbon Corp.

The uses of polyethylene continue to expand although it is now more than ten years since it was first sold in commercial quantities. Originally the material was considered to be most useful because of its low electrical losses. It has been found, however, that its mechanical properties make it an ideal material for a wide variety of uses. Like most new things, many of the uses were developed with a minimum of scientific or engineering background. When some of these early applications apparently resulted in failure it was realized by many people that a better understanding of the mechanical nature of polyethylene would be necessary in order to insure its proper use as an engineering material.

MANY OF THE EARLY investigators considered polyethylene to be "rubber-like" because of its low stiffness or low apparent modulus of elasticity. Tensile tests performed at high rates of straining using standard rubber testing equipment apparently confirmed this belief when elongations at fracture of 400 and 500 per cent were reported. When carbon black was dispersed in polyethylene in order to improve its resistance to weathering, the similarity between polyethylene and rubber was increased still further because of the appearance of the finished product.

Later it was realized that polyethylene more nearly resembled some of the soft non-ferrous metals.[1] It has a non-linear stress-strain curve and great ductility. The analogy may be carried even further since polyethylene has some degree of crystallinity [2,3,4] and, in common with metals, it is also susceptible to the phenomenon of "stress-cracking" or "stress-corrosion"[5]. Like many plastics and glass, however, as well as some metals, notably lead, the mechanical properties of polyethylene are greatly dependent upon the speed of application of the load, and the temperature of testing.

Static Tensile Properties and Tests

The tensile properties of compression-molded polyethylene are usually described by means of a stress-strain curve such as that shown in figure 1.[5] This curve may be roughly divided into three regions as follows:

1. From zero to 50 percent strain, a "pseudo-elastic" behavior is observed. A rapid increase in load with comparatively little strain is followed by a general yielding producing a sharp "knee" similar to that observed in many metals.

2. From 50 to 350 percent strain, the material flows and deforms "plastically." The initial yield point is often followed by a drop in load and a lower yield point. Reductions in area become apparent and "necking" occurs.

3. From 350 percent to failure, increasing loads are observed. This region of the curve is greatly affected by the geometry of the specimen and techniques of testing. At these extreme elongations, stress-strain curves of polyethylene, or of any yielding materials, are of questionable validity since localizations of strain (necking) render strain measured between gage marks meaningless.

Although curves such as figure 1 are very useful, the region between zero and 20 percent strain, the "elastic" region, of prime importance in practical applications, is so condensed that no accurate information concerning this region can be obtained. By using higher strain magnification and slower testing speeds, stress-strain curves of the type shown in figure 2 and 3 have been obtained for injection molded polyethylene. By means of such stress-strain curves, the properties of several grades of polyethylene have been studied over a temperature range from -60°C. to +80°C.

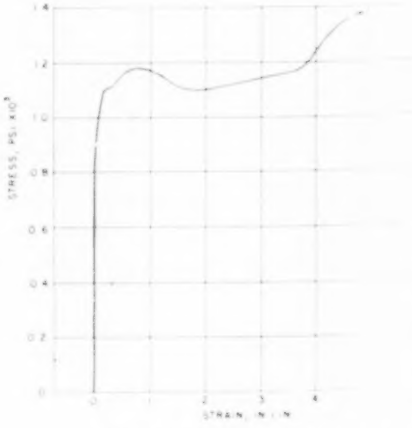


Figure 1. Typical low Magnification Stress-Strain Curve for a Bakelite Polyethylene Compound

effects of temperature are qualitatively indicated by a comparison of figures 2 and 3. Near room temperature the curve is exponential and shows no well-defined yield point. At lower temperatures, however, in addition to an increase in the stress at any given strain, there is a change in the shape of the curve. Instead of being exponential the initial portion of the stress-strain curve is quite linear and extends to high stresses. The "knee" of the curve is sharper and a well-defined yield point is observable at about 7% strain.

As figure 3 and the above discussion show, the stress-strain curve for polyethylene at low temperature is characterized by an initial straight line portion. At these temperatures, therefore, the elastic modulus in tension is calculable by the well-accepted technique of drawing in the initial slope. The procedure is illustrated by the dotted line in figure 3. Young's modulus calculated this way will be referred to as the initial tangent modulus. This technique of evaluation is satisfactory from -60° to about -30°C.

Above -30°C., a straight line portion is no longer observable. It is evident that an extrapolation technique is necessary in order to obtain an initial modulus value comparable to the tangent modulus used at low temperatures. The nature of the stress-strain curve suggests an exponential behavior. By numerically differentiating the stress-strain curve and plotting the logarithm of the slope against the strain a linear relation was obtained. This is illustrated by a typical example in figure 4 for the stress-strain data represented by the curve of figure 2. The straight line is well-defined. With E denoting the slope of the stress-strain curve at any strain, which is the tangent modulus at this strain, the straight line of figure 4 means that the following equation holds:

$$E = E_0 \exp. - \alpha\varepsilon$$

where E = tangent modulus at strain ε

E_0 i.e.: is the initial tangent modulus

ε = strain

α = constant, characteristic of the material and temperature of test

The constant, α, is a measure of the curvature in the stress-strain curve and can be used as an index of the curvature in this temperature range. E_0, the modulus extrapolated to zero strain, is a quantity entirely analogous to the initial tangent modulus used in the low temperature range. Reproducibility has been found to be good, with the coefficient of variation approximately equal to 1.5 to 2.5%. This method of evaluation may be used for tensile stress-strain data in the -30°C. to +80°C. region. The equation is to be considered only an empirical equation describing the stress-strain curve as obtained under the conditions of measurements used.

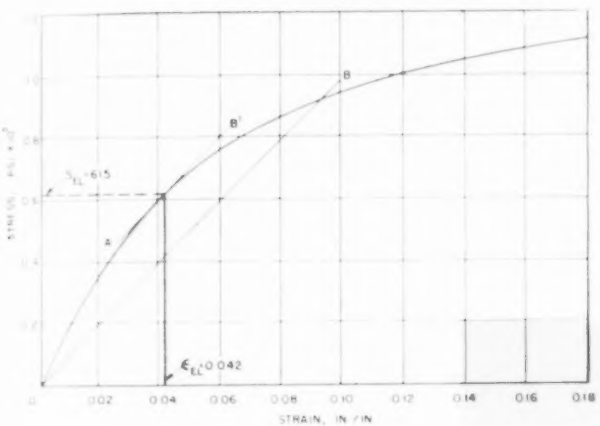


Figure 2. Stress-Strain Curve for D-55 Polyethylene at +25°C. (0.10 in./min.)

Figure 3. Stress-Strain Curve for D-55 Polyethylene at -57°C. (0.10 in./min.) ➤

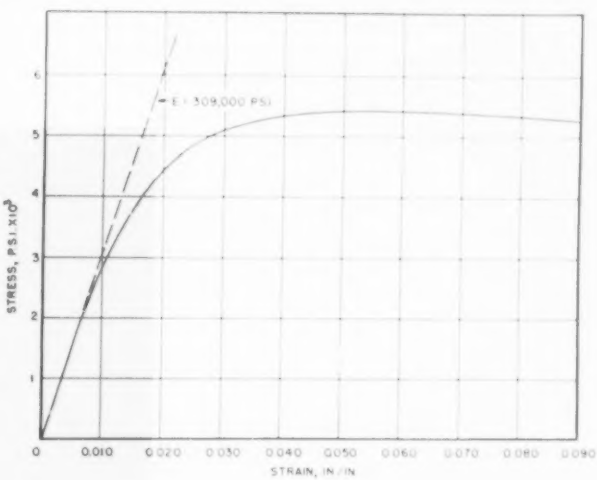
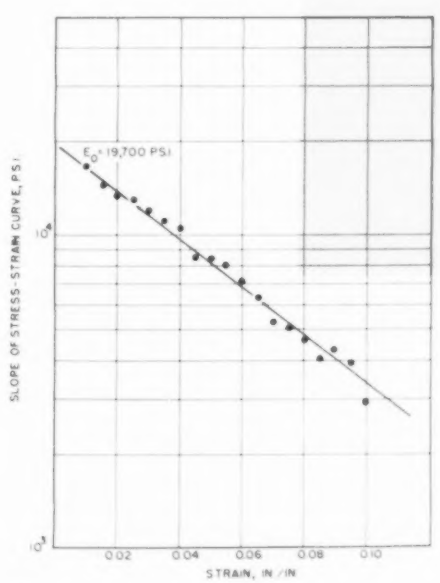
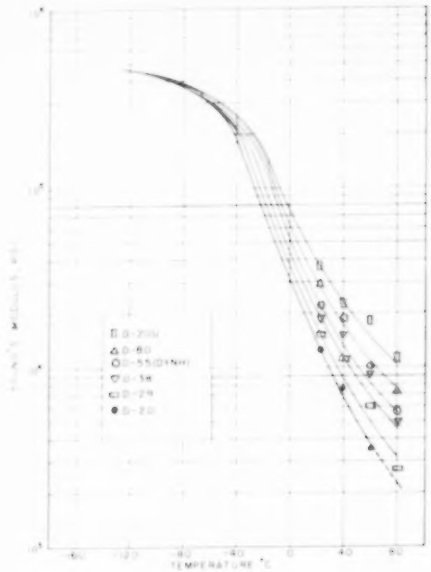


Figure 4. Targent Modulus vs. Strain for D-55 Polyethylene at +25°C.



Stress-strain curves of the type shown in figures 1 and 2 are both necessary in order to understand and interpret the mechanical behavior of polyethylene. In figure 1 for example, the important point to be observed is the initial yield point which occurs at about 1100 psi. At this stress, a potential mechanical instability will be present. This implies immediately that an engineer will be concerned only with stresses less than 1100 psi, and therefore, curves of the type shown in figure 2 are necessary before an engineer can apply that very important quality known as engineering judgement. For curves of the type shown in figure 2, engineers for many years have used many methods for empirically selecting some arbitrary "apparent elastic limit" or "apparent proportional limit." Of these methods, Johnson's method is most suitable since by using it, numbers can be obtained which agree well with field experience. In this method, the "apparent elastic limit" is defined as the stress at that point on the stress-



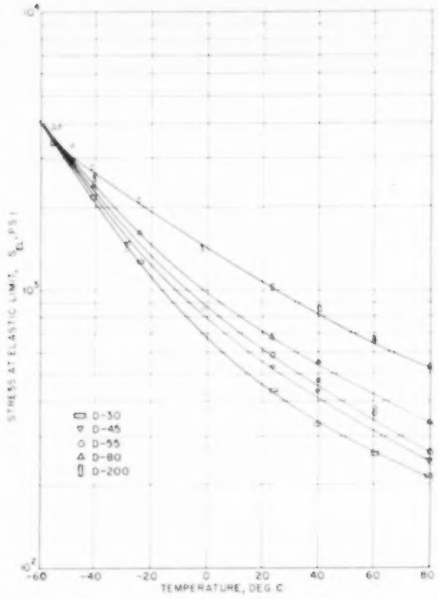


Figure 5. Modulus vs. Temperature for Several Grades of Polyethylene.

Figure 6. Stress at Elastic Limit as a Function of Temperature for Several Grades of Polyethylene.

strain curve where the slope is 50% of the slope at the origin. In other words this is the point where the deformation is increasing, with respect to stress, 50% faster than at the origin. The "elastic limit" as determined by this method is, of course, a very arbitrarily defined point. Nevertheless, it is a point which is indicative of the beginning of general plastic yielding of the specimen.

The numerical differentiation technique as shown in figure 4 has proven to be very satisfactory in routine testing at room temperature. The average laboratory technician has no trouble computing and plotting the points and the extrapolation to zero strain eliminates the uncertainties which are present when constructing graphical tangents to curves of the type shown in figure 2. Once the initial modulus is determined, the 50% modulus is easily computed and the strain at this value may be read directly from figure 4. The stress at the "elastic limit" may then be easily determined from the stress-strain curves like those shown in figure 2. At low temperatures where the straight line portion of the curve is well defined, the graphical construction is most convenient.

Torsion Tests

With conventional testing equipment it is impractical to make tests below -60°C. The temperature range from -60°C. to -125°C. can be covered, however, by using the Clash-Berg[5] or Bakelite Torsion Tester. In order to use this instrument over this range and obtain data which can be compared with tensile results the standard testing techniques must be modified so that torque-angular twist curves are obtained. The slope of these curves, easily obtained by graphical construction, is equivalent to the shear modulus of elasticity. Young's modulus is computed from the shear modulus or rigidity modulus by the following equation (assuming Poisson's ratio to be 0.5):

$$E = 3G$$

E = Young's modulus, psi.
G = Shear modulus, psi.

Stress-Strain Properties as a Function of Temperature and Molecular Weight

Polyethylene resins of several different molecular weights have been investigated over a wide temperature range by the tensile and torsional techniques described

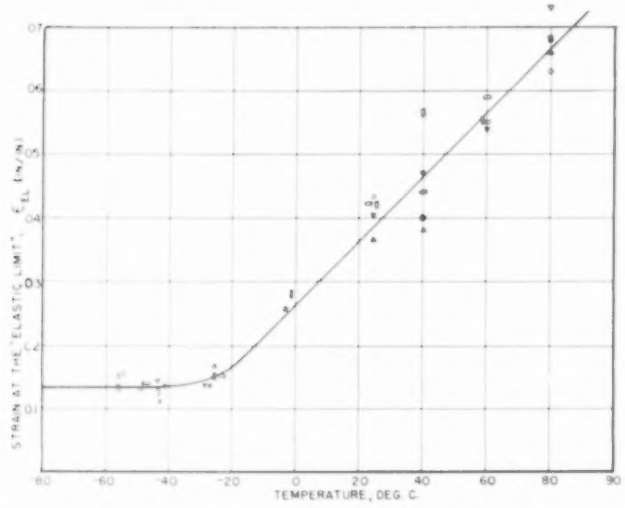


Figure 7. Strain at Elastic Limit as Function of Temperature for Several Grades of Polyethylene.

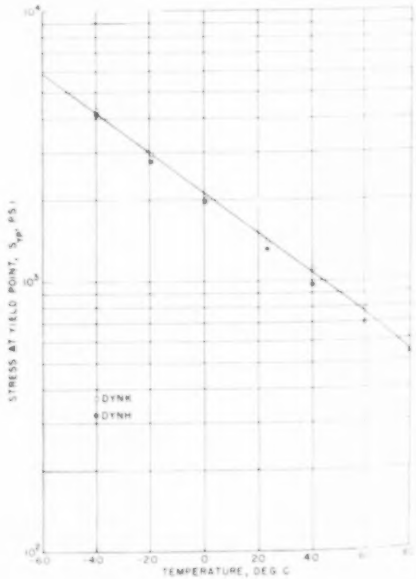


Figure 8. Stress at Yield Point as a Function of Temperature for Several Grades of Polyethylene.

ables. The resins used in this work are designated by the flow height" in mils (0.001 in.) preceded by the letter D as described by Maibauer and Myers.[3] The flow heights are determined by the Williams Plastometer Method. The corresponding relative weight average molecular weights are also listed in Table I as determined by a solution viscosity method as described by Kemp and Peters.[4]

TABLE I

Polyethylene Resins, Grade		Solution Viscosity Average Molecular Weight
D-30		16,000
D-45		19,000
D-55	(DYNH)	20,000
D-65	(DYNJ)	22,500
D-75	(DYNK)	25,000
D-80		26,000
D-100		29,000
D-200		38,000

Modulus

As mentioned before, the initial tangent modulus can be evaluated by several techniques depending on the temperature range covered. From -80°C. to -30°C. the exponential extrapolation method should be used, in the -30° to -60°C. range the initial tangent to the stress-strain curve is evaluated graphically, and in the -25° to -125°C. range the initial torsional modulus is determined. All these data are plotted in figure 5 as modulus versus temperature curves for the different polyethylene resins.

All the data obtained by the different techniques fall along smooth curves. The agreement between the torsional data and the values derived from tensile stress-strain curves is very satisfactory over the common temperature range. On the semi-log scale of figure 5 the curves show the inverted S-shape typical of many plastic materials. The properties of the different molecular weight resins are described by a family of curves quite widely separated at 80°C. merging into a single line below about -50°C. At -50°C., or below, the differences, if they exist, cannot be detected by the testing techniques described here.

No attempts were made to test above 80°C. since polyethylene has a relatively sharp melting point at 100° to 110°C. depending upon molecular weight.

Stress at Elastic Limit and Stress at Yield Point.

Figure 6 illustrates the variation of stress at the "elastic limit" as a function of temperature. These curves are similar in shape and form to the modulus temperature curves, being widely separated at room temperature and converging to a single value at -50°C. It is of interest to observe that all of these resins retain a high degree of strength even at 80°C. a temperature only 20° to 30° below the melting point.

In many engineering problems, the actual load or stress conditions are unknown but the shape and hence the strain in the deformed article is easily measured. For good design this strain should be below the strain at the "elastic limit." Figure 7 shows the variation of the strain at the "elastic limit" as a function of temperature. Within experimental error, the strain is independent of molecular weight.

Figure 8 is a plot of stress at yield point as a function of temperature for two commercial grades of polyethylene. These data were obtained on compression molded samples at a speed of 1 inch per minute using commonly accepted procedures. The yield points, of course, are considerably higher than the "elastic limit" stresses and represent the maximum load obtainable before "necking" or drawing.

Stress-Corrosion-Cracking-Phenomenon

Under conditions of no load, polyethylene is resistant to a wide variety of chemical reagents and shows no loss or gain in weight when immersed in such reagents. The co-incident action of these same reagents and stress, however, may produce the phenomenon known as stress-corrosion-cracking. In certain environments and conditions of stressing, polyethylene suffers a reduction in elongation which is particularly disturbing if judged from the "rubber-like" viewpoint. The "stress-cracking" phenomena[1] were first observed in tests where strips of the sample to to be tested were bent through 180 degrees, scored with a razor and immersed in chemical agents. This method of testing is now a standard stress cracking test. After a period of time, depending upon the resin, the temperature and the chemical agent, fracture (of a brittle nature) occurred on the scored side which was held under a tensile stress. This method of investigating stress-corrosion cracking was of limited value because the actual stress-strain condition was not known and effects of creep and relaxation entered to an unknown extent. A more direct approach was to obtain stress-strain curves of the material while it was immersed in various fluids.

Exploratory tests with tension specimens die-cut from extruded stock showed a much lower breaking strain when tested in ethyl alcohol than when tested in air. Qualitatively, it appeared that the higher molecular weight resins were more resistant to the action of the alcohol. The die-cut specimens, however, possessed many surface irregularities because of the cutting action of the die. Injection-molded tension specimens were then made, and it was found that with no surface imperfections, "brittleness" was not apparent even in the lower molecular weight resins. If the edge of the specimen were nicked or scored, however, fracture occurred in a brittle manner.

Several tests with the nicking technique, although qualitatively indicating "brittleness" did not show sufficient reproducibility to distinguish between resins. Since this nicking technique is difficult to control, it was abandoned and the "stress-raiser" was produced by drilling a 1/16 in. diameter hole through the center of the specimen. With a specimen ½ in wide (⅛ in. thick), the hole diameter-specimen width ratio is then 0.125. This provides an arbitrary geometrical condition which serves to distinguish between materials and is the same order of magnitude as that used in tests of aluminum.[1]

The complete stress-strain curve indicated that the presence of a hole and a chemical agent resulted primarily in a shortening of the curve. The shape of the initial portion was not appreciably altered. These effects were examined with a variety of liquids for five injection molded samples of resins varying in flow height from 0.045 to 0.100 inches.

Samples without a hole broke at elongations of 70 to 140%. This is the elongation expected of injection molded samples and is well below the 400 to 600% commonly reported for extruded or compression molded samples of equivalent molecular weight. Generally, the elongation observed when no hole was present was not affected by the molecular weights or by the surrounding liquid. However, the presence of a hole caused a distinct reduction in elongation. In air, distilled water or soapy water, the elongation was 40 to 50% regardless of molecular weight as shown in Table II. In the alcohols and toluene, however, the elongations, although less than air, are de-

TABLE II

Tensile Breaking Strain of Injection Molded Polyethylene, Nominal Values Over a 2-in. Gage Length-1 16-in. Hole

	Enviroment						
Resin	Air	Distilled Water	Soapy Water	Ethyl Alcohol	n-Amyl Alcohol	t-Amyl Alcohol	Toluene
D-45	51	60	51	18	6	7	14
D-55	62	54	41	38	15	13	18
D-55	39	42	46	36	20	20	14
D-65	45	45	51	44	25	20	21
D-85	42	44	44	40	29	26	20
D-100	48	47	47	44	36	38	38

TABLE III

Tensile Breaking Stress (In PSI.) of Injection Molded Polyethylene, Nominal Values From Net Cross-Sectional Area At Hole

Sample	Air	Distilled Water	Soapy Water	Ethyl Alcohol	n-Amyl Alcohol	t-Amyl Alcohol	Toluene
D-45	1220	1360	1260	1010	790	810	970
D-55	1620	1680	1660	1560	1240	1250	1310
D-55	1780	1830	1740	1660	1420	1400	1330
D-65	1750	1890	1900	1810	1550	1520	1460
D-85	1930	2120	2080	2020	1900	1860	1670
D-100	2160	2250	2240	2210	2080	2100	1900

pendent upon molecular weight. This is particularly true in n-amyl and *tert*-amyl alcohol where regularly increasing elongation occurs with increasing molecular weight.

Table III compares the specimens (with a hole) on the basis of stress. The breaking stress is dependent upon the molecular weight whether tested in air or alcohol. The lowest molecular weight resins are more greatly "embrittled" by alcohol and toluene than the highest molecular weight resins. Stress at fracture follows a more regular pattern with molecular weight than strain at fracture.

The explanation for the behavior discussed above may be found in several texts on engineering materials. Ductile materials which fail primarily by "sliding" or "slipping" can be made to fail like "brittle" materials depending upon the speed of deformation, temperature of testing and the geometry of the piece.

"Plastic" deformation in crystals is usually accompanied by sliding along certain crystallographic planes. Sliding or "yielding" begins when the magnitude of the shearing stress reaches a limiting value. In so-called "brittle" materials, stretching due to sliding is small, and fracture occurs by overcoming cohesion and the material has a brittle fracture. The type of fracture occurring is very dependent upon the method of testing. A "ductile" material may have a brittle type of fracture if the form of test specimen or type of stress distribution is such that deformations due to sliding are prevented.

The maximum shearing stress is equal to $(Sx - Sy)/2$ where Sx and Sy are the maximum and minimum principal stresses.[13] In a simple tension test, the shear stress is one half of the tensile stress. In such cases sliding occurs and a shear or "ductile" type failure results. If the principal stresses are nearly equal, however, the shear stress is near zero and fracture occurs on the plane of maximum tensile stress before sliding can occur and the fracture is termed "brittle." Because of necking, nicking, or other geometrical factors producing an irregularity in shape, some specimens apparently subject to uniaxial tension are actually subject to bi- or tri-axial stressing.[14] Under such conditions the shear stresses are near zero and the material cracks or exhibits a "brittle" fracture.

For these reasons, it is necessary that the complete stress-strain curve of polyethylene should be well understood. The alcohols and solvents used in these tests show their effect principally in a shortening of the stress-strain curve. That is, whether tested in alcohol or air, the initial part of the curve is very similar. Yielding or sliding is somehow prevented by the "solvents" and the material fractures in a brittle manner.

Undoubtedly, time is an important factor in "embrittlement." No attempt was made in these experiments to control this factor other than to make all tests at the same rate of straining (0.1 in. per min.), and to avoid unduly long immersions. The actual immersion time was about 2 to 10 minutes.

Creep and Stress Rupture Properties

The creep and stress rupture properties of polyethylene and polyethylene compounds are of primary interest to all engineers. Gohn, Cummings and Ellis[1] have obtained creep data at 85°F., on compression molded sheet stock made with and without antioxidants and carbon black. The creep characteristics of these materials are much the same and for all practical purposes the data may be considered as being representative of the creep of commercial molecular weight grade of polythylene such as DYNH.

Typical creep curves (at 85°F.) are given in figure 9 for tensile stresses of 200, 400, 600 and 800 psi. The creep curves show an instantaneous elongation whose magnitude increases with increasing stresses. At zero time, this is approximateiy equivalent to the elongation obtained in a static tensile test. The instantaneous elongation is followed by further increase in strain which continues at a decreasing rate, dependent upon the stress. At the higher stresses (600 and 800 psi.) it requires about 2000 hours to complete the initial extension or first stage of creep. At low streses, this initial extension is completed in a relatively short time. In the second stage of creep there is a slow extension during which the creep rate decreases gradually and approaches a constant rate or straight line.

creep curves of figure 9 are interpreted by plotting the creep rate or slope of the straight line portion as a function of the applied stress. This is shown in figure 10. For most engineering design work it is also important to know the total extension occurring after a given period of time. Gohn, Cummings and Ellis have plotted total extension as a function of stress after 10,000 hours elapsed time as shown in figure 11. Figure 11 shows that at 800 psi. the total extension in 10,000 hours is as great as 60% but that at 300 psi. it is only 4%.

The short and long time properties of polyethylene may be conveniently compared by constructing a psuedo "stress-strain" curve from the creep data. Figure 11 supplies data for the total strain after 10,000 hours (1.1 years) of creep at 85 F. and the stress producing this strain. The long time "stress-strain" properties are shown in figure 12 and are contrasted with the short time properties (at 77 F.) which were discussed in the first part of this paper. The imperfect "elastic" nature of polyethylene is well illustrated by this plotting. Unfortunately there is again no definite demarcation between "elastic" and "inelastic" behavior. The engineer who uses these data will have to interpret it to suit his particular problem. The total elongation (creep) at 200 psi. and 400 psi. is approximately equal to the value obtained in static tensile tests. At 800 psi. the total elongation (creep) is much greater than that obtained in a static test. At 600 psi. a borderline condition exists which the engineer must evaluate for his particular application. It should be observed that all the stresses shown in figure 12 are less than the yield point and that no fractures occurred even when the samples were held under these stresses for a year.

Creep data, although of interest in many problems, do not necessarily provide any information about fracture or failure. Stress rupture and stress-corrosion-rupture tests by Ellis and Cummings[15] performed on compression molded tensile specimens and hydrostatically inflated pipe samples, give this kind of information.

Tensile "stress-corrosion-rupture" tests were made on

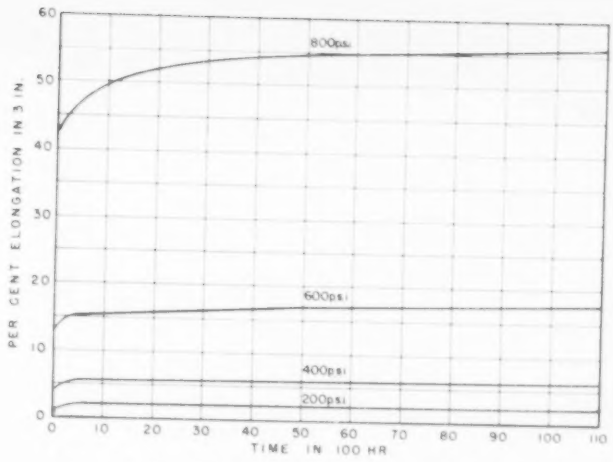


Figure 9. Creep of Polyethylene at 200, 400, 600 and 800 psi.

specimens having a polyaxial stress condition introduced by four transverse slits cut (0.010 inches deep) across the width of the tensile specimen. The edges and surface of the specimens were then treated with Igepal CA Extra, a known deleterious surface active agent which provides a powerful cracking environment. Figure 13 shows the results of their work. Specimens not coated with the cracking agent did not fail at 16,000 hours when stressed at 600, 400 and 200 psi. Specimens coated with Igepal CA Extra when stressed between 500 and 800 psi. failed in less than one half hour with elongations between 6.5 and 16%. At 400 psi., the data are scattered but failures took place at 3% strain. The curve reaches an asymptote at about 250 psi. which indicates there will be no fractures below this stress for an indefinitely long time.

The pipe stress-corrosion-rupture tests were made on tubes of polyethylene, 2¾ in. outside diameter and 0.125 in. wall, which were obtained by removing the inner wires

(please turn to page 41)

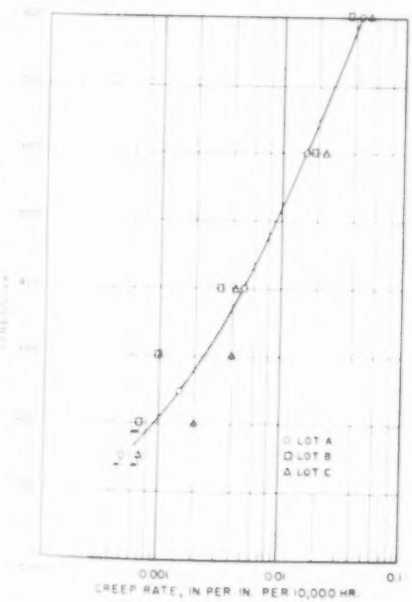


Figure 10. Creep Rate, Inches per Inch per 10,000 Hours, as a Function of Applied Stress.

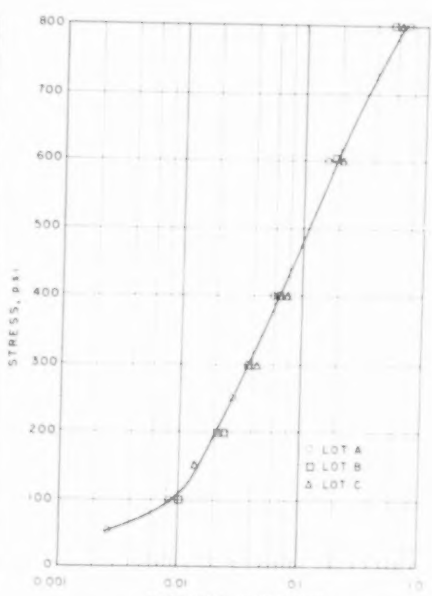


Figure 11. Total Extension, Inches per Inch after 10,000 Hours as a Function of Applied Stress.

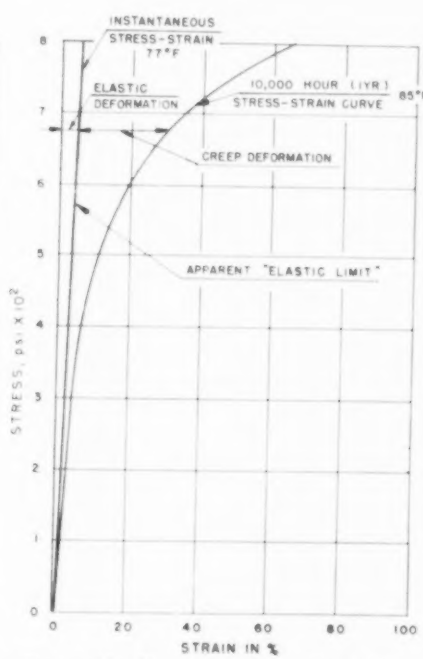
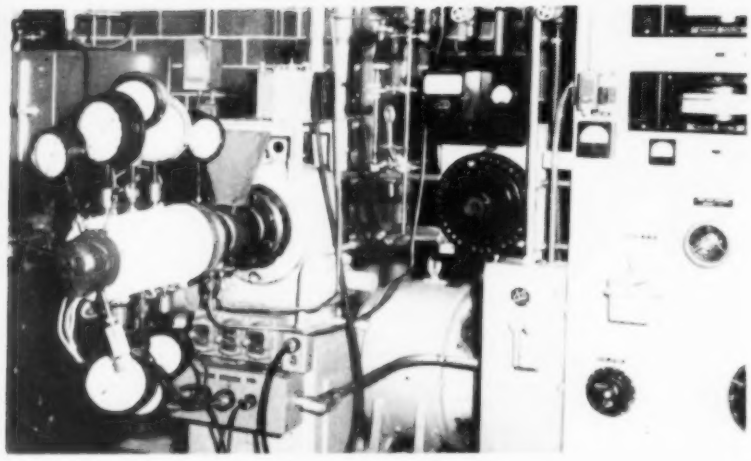


Figure 12. Short and Long Time Stress-Strain Curves of Polyethylene.



Adiabatic

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In its broadest terms, a complete extrusion theory would permit all the performance characteristics of extruders to be calculated if the following data were known.

(1) The dimensions of the extruder, the screw, and the die

(2) The thermal, viscous, and mechanical properties of the plastic

(3) The operating conditions of the extruder, such as the screw speed and the power supplied to the barrel heaters

(4) The entering temperature, pressure, and state of aggregation of the plastic.

We believe that such a theory may never be completely developed. Certainly, our work falls far short of being a complete theory and we have taken a much more modest approach to the problem. Our approach has been to consider separately the various zones of an extruder, such as the feed pick-up zone, the compression zone, the metering zone, and the die. For each of these zones we postulated certain idealized conditions and then attempted to find mathematical solutions that would be valid for the postulated conditions.

At first, much of our attention was directed to the metering zone, as we believe that quite often the metering zone controls the overall extruder performance. The metering zone of the screw is located just before the die. In this zone the plastic is a viscous fluid. Since viscous flow theory has a sound theoretical background, we were able to draw upon this for help in the derivation of equations describing the behavior of the plastic in this zone. Consequently, problems of viscous or melt flow were the most amenable to successful mathematical solutions. Our initial report[1] on this work consisted of an analysis of isothermal melt flow. Results obtained from experiments on extruders which were fed viscous liquids and operated at near-isothermal conditions verified these melt flow equations. We next considered the case of adiabatic extruder operation. A mathematical analysis[2] of adiabatic operation of melt extruders was reported last fall. Considerable data have now been collected from polyethylene extrusion experiments in which the extruder was operated under near-adiabatic conditions, and in this paper these data are analyzed in terms of the adiabatic melt flow theory and conclusions are drawn as to the usefulness of the adiabatic theory in practical extrusion problems.

A. Energy Relationships in Extruders

BEFORE PRESENTING THE equations for adiabatic operation it will be helpful to discuss some general energy relationships which apply to any type of extruder operation. Figure 1 is a schematic diagram of a screw extruder. The screw rotates at N revolutions per unit time driving the plastic melt through the die at the volumetric flow rate **Q**. The rotation of the screw is maintained by expending mechanical energy at the rate **Z**. Heat is generated in the molten plastic through viscous shearing, causing its temperature to rise as it advances along the helical channel of the screw. Heat can also be added or removed from the plastic by transfer **from** external heaters or **to** external coolers. **q** represents the net rate of heat transfer obtained by summing up, over the entire extruder, all of the local heat transfer rates.

The net rate of change of heat energy of the plastic as it passes through the extruder is **C Q Δ T, where Δ T** represents the change in temperature of the plastic and **C** is its heat capacity. The increase in pressure energy of the plastic is **Q Δ P**, where **Δ P** is the increase of pressure of the plastic. An energy balance can be written over the entire extruder in which the rate of increase of heat and pressure energy of the plastic is equated to the input rate of mechanical and heat energy.

$$CQ\Delta T + Q\Delta P = Z + q \tag{1}$$

This is the general over-all energy balance applicable to any type of extruder operation. A small kinetic energy term has been neglected, as well as a small **P Δ V** term which would account for the decrease in melt density.

For isothermal operation (**Δ T = 0**), the melt temperature is constant throughout the extruder and it is apparent that all heat generated in the plastic by mechanical working must be removed by transfer. Therefore, **q** must be negative, and the over-all energy balance reduces to,

$$Q\Delta P = Z - q \tag{2}$$

In purely adiabatic operation, all of the heat and pressure energy arises from mechanical working and no heat is transferred either to or from the plastic. Con-

1. "Symposium on the Theory of Plastics Extrusion," **Ind. Eng. Chem., 45**, 969-993 (1953).
2. McKelvey, J. M., "Theory of Adiabatic Extruder Operation," paper Presented on September 1953 at the Chicago ACS meeting. Accepted for publication in Ind. Eng. Chem.

Extrusion of Polyethylene . . .

separately, q is zero and the energy balance for adiabatic operation is written,

$$CQ\Delta T + Q\Delta P = Z \qquad (3)$$

B. The **Equations for Adiabatic Operation of Melt Extruders:**

Referring to Figure 1 again, we see that z is the coordinate axis along the helical channel. Consider a small incremental length, **dz**, at any position along this axis. Through the length **dz**, the pressure rises an amount **dP**, the temperature rises an amount **dT**, and **dZ** units of power are used in shearing the molten plastic. The volumetric flow rate through the section is given by the equation,

$$Q = \alpha N - \frac{\beta+\gamma}{\mu}\left(\frac{dP}{dz}\right) \qquad (4)$$

and the power dissipated in the length dz is given by the equation,

$$dZ = \epsilon N^2 \mu dz + \frac{\alpha N dP}{\cos^2\theta} \qquad (5)$$

The constants α, β, γ, and ε are functions only of the dimensions of the screw and are known as the screw constants. The equations defining the screw constants are listed in Table I.

TABLE I

EQUATIONS DEFINING THE SCREW CONSTANTS

DRAG FLOW CONSTANT:	$\alpha = (\frac{1}{2})n\pi Dh(\frac{t}{n} - e)\cos^2\theta(\frac{h}{h+\delta})$
PRESSURE FLOW CONSTANT:	$\beta = (\frac{1}{12})nh^3(\frac{t}{n} - e)\cos\theta$
LEAKAGE FLOW CONSTANT:	$\gamma = \frac{\pi^2 D^2 \delta^3}{10e}(\frac{h}{\delta})^{\frac{m-1}{m}}$
POWER CONSTANT:	$\epsilon = n\pi^2 D^2 \cos\theta\left[\frac{\frac{t}{n} - e}{h} + \frac{e}{\delta}(\frac{h}{\delta})^{\frac{1-m}{m}}\right]$

A word concerning the calculation of the constants γ and ε is needed here. These constants contain the factor (h/δ) raised to the $(m-1)/m$ power which has been added to make the equations fit better for non-Newtonian flow.

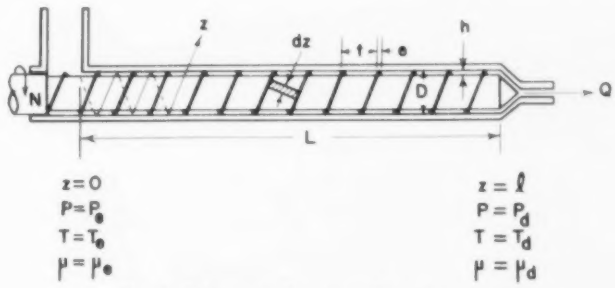


Fig. 1. Schematic Drawing of An Extruder

LIST OF SYMBOLS AND RECOMMENDED SYSTEM OF UNITS

SYMBOL	DEFINITION	UNITS
C	Specific Heat of Molten Plastic	in-lbs/in³-°C
D	Diameter of Extruder Barrel	in
L	Length of Screw	in
N	Screw Speed	rps
P	Pressure	psi
Q	Volumetric Extrusion Rate	in³/sec
T	Temperature	°C
Z	Mechanical Power	in-lbs/sec
b	Temperature Coefficient of Viscosity	(°K)⁻¹
d	Diameter of Cylindrical Dies	in
e	Width of Flight Land	in
h	Depth of Screw Channel	in
k	Die Flow Constant	in⁵
l	Length of Helical Screw Channel	in
m	Polymer Flow Constant (m = 1 for Newtonian Liquids)	-
n	Number of Parallel Screw Flights	-
q	Rate of Heat Transfer	in-lbs/sec
t	Lead of Screw Flight	in
z	Variable Distance Along Helical Channel	in
α	Drag Flow Constant	in³
β	Pressure Flow Constant	in⁴
γ	Leakage Flow Constant	in⁴
δ	Radial Clearance	in
ε	Power Constant	in³
μ	Viscosity	lbs-sec/in²
θ	Helix Angle	-
P(d)	Pressure at Extruder Die	psi
T(d)	Temperature at Extruder Die	°C
μ(d)	Melt Viscosity at Extruder Die	lbs-sec/in²
L(d)	Length of Extruder Die	in

The constant m is a function of the viscous flow behavior of the plastic and is defined by the so-called "power law."

$$\text{Shear Stress} = K\,(\text{Shear Rate})^m$$

For simple Newtonian liquids, **m** becomes equal to 1.0 and the correction factor drops out. For polyethylene, **m** is the range of about 1.5 to 3.0. We used a value of 2.2 in the calculations.

The derivation of the adiabatic extrusion theory is based on the integration of equations 4 and 5 with respect to the channel length **z**. Since there are five variables involved, three more idependent equations involving these variables must be developed before the integrations can be performed. One of these additional equations is the energy balance over the incremental length of the screw channel,

$$(6) \qquad CQ\,dT + Q\,dP = dZ$$

Another equation can be written relating the flow and pressure at the extruder die,

$$(7) \qquad Q = k\frac{P_d}{\mu_d}$$

where **P(d)** is the pressure at the die and μ**(d)** is melt viscosity of the plastic at the die. **k** is known as the die constant and is easily calculated for certain simple geometric shapes. For example, for cylindrical dies k is defined by the equation

$$(8) \qquad k = \frac{\pi\, d^4}{128 L(d)}$$

where **d** is the diameter of the die and **L(d)** is the length.

Finally, an equation which relates the melt viscosity to temperature is required.

$$(9) \qquad \mu = \mu_e e^{b(T_e - T)}$$

where **b** is called the temperature coefficient of viscosity, μ is the viscosity at any temperature T, and μ **(e)** is the viscosity at some reference temperature **T(e)**. Equation 9 is an empirical equation which has been found to correlate temperature-viscosity data for plastics quite well over the temperature ranges that are of interest in extrusion.

These five equations are the basis for the derivation of the adiabatic extrusion theory. This derivation has been presented elsewhere[2], and only the final results are reproduced here in Table II.

C. Adiabatic Operation of Plasticating Extruders:

The theory of adiabatic extruder operation was derived on the basis of viscous flow and applies, rigorously, only to **melt extrusion** (i.e., to operations where the material enters the extruder in the molten state). Therefore, before describing our experimental work on **plasticating extrusion**, it will be helpful to discuss some of the problems involved in extending melt flow theory to include the case of plasticating extrusion.

For adiabatic melt extruders, the theory enables us to calculate the relationship between the pressure, temperature, extrusion rate, screw speed, and the screw and die constants. This relationship is clearly illustrated by a diagram of the type shown in Figure 3, where the ordinate is the extrusion rate and the abscissa is the temperature rise of the molten plastic. Figure 3 represents a typical theoretical performance diagram for an adiabatic melt extruder. The heavy line at the left is the free discharge line and shows how the extrusion rate and temperature increase as the screw speed increases. Similarly, the other lines, also radiating from the origin, show this relationship for extrusion through dies of various resistances.

The lines which intersect the free discharge line connect points of equal screw speed and show how, at a given speed, the extrusion rate and temperature change as the die resistance changes. Once such a diagram is constructed for a given extruder, the extruder operating point can be quickly located for any combination of screw speed and die resistance. For example, assume that the extruder is operating at speed N_2 and that the die resistance is k_1. The intersection of these two lines, point A, is the extruder operating point.

TABLE II

EQUATIONS FOR ADIABATIC EXTRUDER OPERATION

$$\Delta T = \frac{1}{b}\ln R$$

$$Q = \frac{MN^2 I}{R-1}$$

$$P_d = \frac{\mu_e Q}{kR}$$

$$Z = CQ\Delta T + QP_d$$

Values of R must be calculated from the equation,

$$\left(\frac{\beta+\gamma}{kI}\right) = \left(\frac{\alpha}{MNI}\right)R\ln R - \frac{R\ln R}{R-1}$$

or are obtained from the graph shown in Figure 2.

The parameter M is defined by the equation,

$$M = \frac{\mu_e b\epsilon}{C}$$

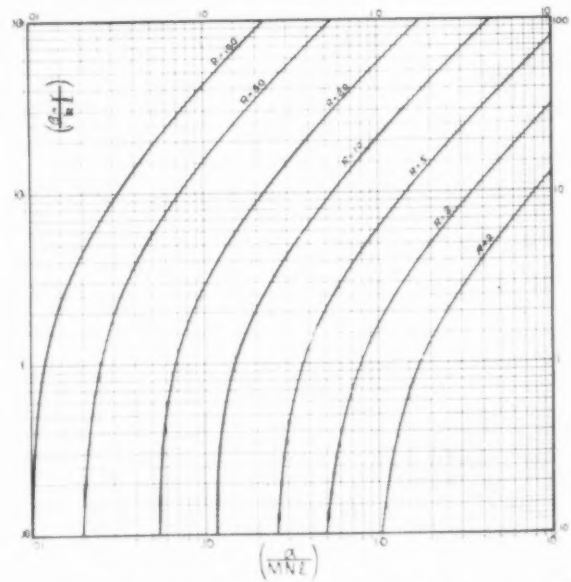


Fig. 2. Chart for Determining values of the Parameter P

diagram illustrates how it would be possible control independently the extrusion temperature and extrusion rate, without using external heaters. This of the potentials of adiabatic operation. Control extrusion rate and temperature can be obtained by regulating the screw speed and the die resistance. How can the die resistance be regulated? One way to vary the number and size of screens in the screen pack. A more flexible arrangement, though, would be to have a control valve located between the end of the screw and the die. In this way, by regulating the control valve and the screw speed, any combination of extrusion rates and temperatures can be obtained.

Another advantage of adiabatic operation lies in the manner in which heat is added to the plastic melt. If external heaters are used to increase the melt temperature, large temperature gradients may be set up. On the other hand, if the temperature is increased by dissipating mechanical energy in the melt through viscous shearing, no temperature gradients are necessary, and the entire melt can be maintained at a much more uniform temperature. This is a considerable advantage in the extrusion of thermally sensitive plastics and for the high temperature extrusion of any plastic.

Consider now plasticating extruders. Two questions arise. Can plasticating extruders be operated adiabatically, and, if they can, is it possible to extend the adiabatic melt theory so that it adequately describes adiabatic plasticating extrusion?

Consider the first question. The answer is that sometimes plasticating extruders can be operated adiabatically and sometimes they can't. It all depends upon the properties of the plastic, particularly the solid state properties. To obtain adiabatic operation in a plasticating extruder, it must be possible to deform and shear the solid plastic at low temperatures and thereby generate sufficient internal heat to melt it. On the other hand, plastics that are hard and rigid in the solid state are very difficult to shear and work in extruders, and heat transfer must be relied upon to supply most of the energy needed to melt them.

Realizing that with some materials it is possible to operate plasticating extruders adiabatically, are there any further advantages, aside from more uniform heat generation, to be gained by this mode of operation? There is one great advantage which concerns the extruder capacity. The flow theory for the metering zone shows that the melt pumping capacity of a screw is directly proportional to the speed of rotation. Therefore, the capacity of an extruder which is able to generate, through mechanical working, all of the heat needed to melt the plastic does not depend on heat transfer and the capacity is limited only by the maximum speed of the screw.

On the other hand, if we have an extruder in which the plastic is melted primarily with heat which is transferred through the barrel, then increasing the screw speed will have little effect on the melting capacity. True, the overall coefficient of heat transfer may increase with speed, but probably not enough to keep up with the increase in pumping capacity. In other words, when predominantly transferred heat is utilized to melt the plastic, the rate of heat transfer controls or limits the ultimate capacity of the extruder.

If this dependence on transferred heat could be avoided, much higher ultimate capacities could be obtained. Adiabatic operation removes this dependence, since there is a second-power relation between the amount of mechanical working and the speed of the screw. Therefore, much higher ultimate capacities of plasticating extruders can be obtained by high-speed adiabatic operation in which most of the heat is generated mechanically. For example, as a demonstration, we have operated our 2-inch diameter extruder under nearly adiabatic conditions at high speeds and have obtained polyethylene extrusion rates of well over 100 pph. These results will soon be discussed in more detail.

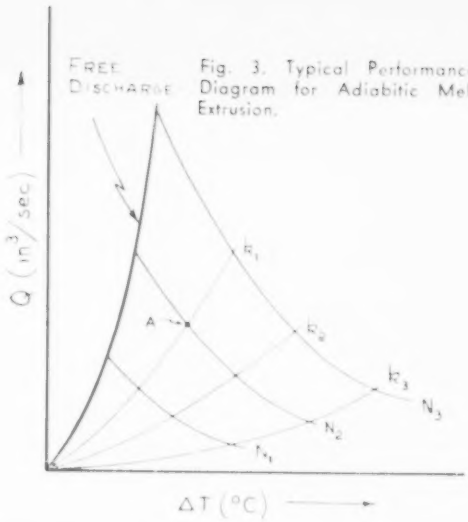


Fig. 3. Typical Performance Diagram for Adiabitic Melt Extrusion.

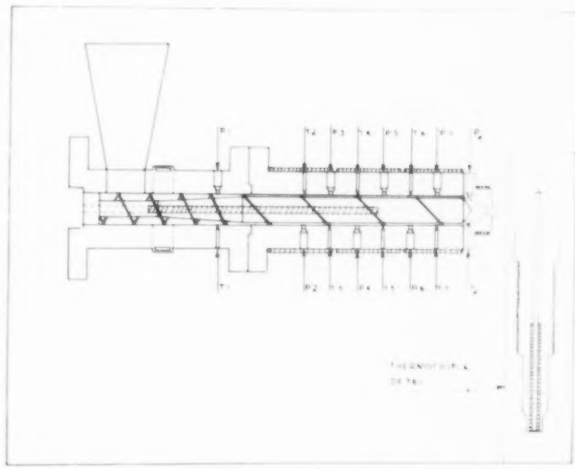


Fig. 4. Experimental Extruder

Adiabatic operation of plasticating extruders appears to be an attractive idea. Of course, the building of high-speed, high-capacity adiabatic extruders will involve much development work. It is critical that the screw be properly designed for the type of plastic that will be extruded. The relationship between the performance of the machine and the design and operating variables is complicated, and designing extruders for adiabatic operation by trial and error is not recommended. Therefore, the question is, can the adiabatic melt theory be used as a design basis for plasticating extruders? This is the question that we have tried to answer with the experiments reported in this paper. These experiments were performed with polyethylene both because it has properties that make it easy to deform and shear it in the solid state and because of the commercial importance of polyethylene extrusion.

II. EXPERIMENTAL

A. Apparatus:

Figure 4 is a diagram of the extrusion equipment that was used for the experimental program.

Extruder Barrel: A special 2-inch-diameter barrel de-

signed so that measurements of the temperature and pressure of the plastic melt can be made at various locations along the length of the screw was used. These measurements are made with themocouples and pressure gages which pass through the barrel wall so that their tips are in contact with the molten plastic. There are 7 thermocouples and 7 pressure gages spaced alternately along the length of the barrel, as shown in Figure 4.

Barrel heating is provided, from the flange forward, by six 220 volt band heaters, each of 1000 watts capacity, giving a total heater capacity of 6 KW. Barrel cooling, in the vicinity of the feed hopper, is obtained by circulating cooling water through an annular ring located just in front of the feed hopper. The cooling water flow rate is measured with a rotameter and the temperature rise of the water as it passes through the ring is measured with thermocouples located in the water line at the inlet and outlet connections to the ring.

Extruder Drive: The extruder drive consists of a motor-generator set, capable of delivering up to 15 HP to the gear reducer, which is a standard type supplied with a No. 1 Royle extruder. The sheaves were changed so that operating speeds up to 190 rpm could be obtained.

Extruder Head: The head holds the extruder die and also serves to streamline the melt flow from the end of the screw to the die. Its temperature is controlled with a 110 Volt-250 Watt band heater. The extrusion dies screw into the front of the head so that the axis of the die orifice is in line with the axis of the screw. A set of 6 single-orifice dies was used in the experiments. Their dimensions are listed in Table III.

The flange of the head is drilled and tapped to hold the die pressure gage, the die thermocouple, and a rupture disk assembly.

The rupture disk assembly consists of a tube, filled with silicone grease, which screws into the head flange. A disk, rated at 6700 psi bursting pressure is located at the other end of the tube. This system was installed to eliminate any possible danger from excessive pressures that would be generated if the die orifice should become clogged with dirt or other foreign matter.

The die thermocouple consists of a $\frac{1}{8}$ inch iron tube containing a constantan wire, with the iron and the constantan brazed together at the tip. The thermocouple extends into the melt flow stream for a distance of about one inch; this minimizes errors due to heat conduction along the iron tube.

The die pressure gage is identical to those used along the barrel and is described later.

Screws: Three different screws were used. Figure 5 is a diagram showing the general design of these screws. The metering zones of the screws are identical except for the depth of the channel. The dimensions of the metering zones are summarized in Table IV. Screw 2-X-1 is single-flighted with a 17.8° helix angle in the feed and compression zones. The other two screws are double-flighted and have 30° helix angles in the feed and compression zones. All of the screws have $\frac{3}{8}$-inch diameter hollow cores which accommodate 110-volt, 600-watt electric cartridge heaters. The heater lead wires are connected through slip rings at the rear of the screw.

Pressure Gages: Pressure measurements were made with modified Carley type gages. The Carley[3] method utilizes Bourdon tubes filled with silicone grease. Pressure is transmitted to the Bourdon gage through a pressure transmitting tube which is also filled with silicone grease. The end of the pressure transmitting tube extends through the barrel wall and is flush with the inner barrel surface. In the Carley system, the transmitting tube is fitted with a piston, which prevents the grease from leaking into the plastic or the plastic from leaking into the grease. However, we found, that over extended periods of operation, the annular space between the piston and the tube wall would become clogged with plastic and would retard or jam the movement of the piston. Therefore, we removed the piston from the transmitting tube and allowed the plastic melt to come into direct contact with the silicone grease. We found that grease losses from the assembly were negligible and occurred only at the very beginning of a run. Traces of grease were some-

3. Carley, J. F., **Ind. Eng. Chem., 45**, 858 (1953).

TABLE III
Extrusion Dies

Die No.	Diameter (in)	Length (in)	K x 10^6 (cu in)
1	.0469	1.00	0.12
2	.0625	1.00	0.38
3	.0938	1.00	1.90
4	.1250	1.00	6.00
5	.1875	1.00	30.0
6	.3750	1.00	490

TABLE IV
Screw Dimensions

		2-X-1	2-X-2	2-X-3
D(o):	Root Diameter	1.749	1.876	1.928
D:	Outside Diameter	1.983	1.990	1.994
h:	Channel Depth	0.117	0.057	0.033
δ:	Radial Clearance	0.009	0.005	0.003
e:	Axial Land Width	0.432	0.288	0.288
n:	Flights in Parallel	1	1	1
t:	Flight Lead	3.60	3.60	3.60
θ:	Helix Angle	30°	30°	30°

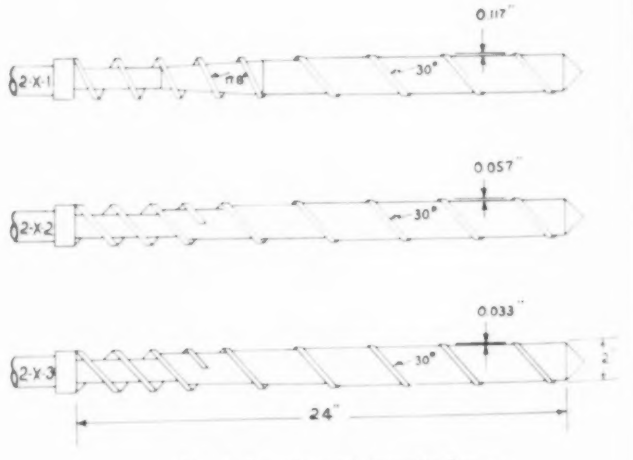


Fig. 5. Experimental Extruder Screws.

times observed during start up operations, but after a few minutes they disappeared. The response of the gages with pistons was much faster than with pistons.

Thermocouples: The thermocouples used for temperature measurements along the barrel consisted of a $\frac{1}{8}$-inch iron tube containing a constantan wire brazed to the iron at the tip. The iron tube is insulated from the barrel metal by a sleeve of "Teflon" polytetrafluoroethylene resin. A sketch of the thermocouples is shown in Figure 4.

B. **Procedure:**

A single large lot of "Alathon" polyethylene resin, having a melt index[4] of 2.0, was obtained for the experimental program. The melt index is a measure of the amount of polyethylene which will flow through a standard orifice, at a standard temperature, and under a standard pressure, in a given length of time. It partially characterizes polyethylene resins. Polyethylene of melt index 2.0 is representative of a commercial du Pont resin.

For each run the system was first preheated by applying a high voltage to the barrel heaters. The cooling water flow rate was adjusted so that the barrel temperature at thermocouple location No. 1 was maintained in the range of 110°C to 130°C. When the barrel reached the proper temperature the drive was started and adjusted to the desired speed. The barrel heater voltage was then reduced to about 10 to 30 volts and maintained there for the remainder of the run. The exact voltage selected depended on the extrusion temperature. The objective was to use the barrel heaters merely to make-up heat losses due to radiation and conduction. Cube-cut polyethylene was then fed to the hopper and temperature, pressure, flow rate, and screw speed was measured and recorded at 15 minute intervals. Screw speed was determined by timing screw revolutions with a stop watch. Flow rates were measured by weighing timed samples of the extrudate. All temperatures were read on a potentiometer connected through a selector switch to the thermocouples. Pressures were read directly from the pressure gages.

As soon as three consecutive sets of measurements were obtained in which there was no change in the readings, it was assumed that the extruder operation was in equilibrium and the measurements were recorded.

4. Jolly, R. E., and Tordella, J. P., **Modern Plastics**, 31, 146 (1953).

III. DISCUSSION OF RESULTS

A. **Internal Screw Heater:**

Previous experiments had shown that the relatively short compression zones of the screws were unable to melt and push forward polyethylene as fast as the metering zone could pump the molten material through the die. This effect was particularly noticeable at low extrusion pressures where back flow is small and the capacity of the metering zone is high. Under these conditions, the extrusion rate was severely limited by the capacity of the compression zone. We found that this limitation could be overcome by heating the screw at the compression zone and we installed 110-volt 600 watt cartridge heaters in the core of each screw.

The heater was positioned approximately as shown in Figure 4. The heater lead wires were connected, through slip rings, to a transformer so that any desired voltage, from 0 to 135, could be applied to the heater. Experiments showed that the performance of the extruder operating at low die pressures could be drastically changed by varying the voltage applied to this heater. Figure 6 is a plot of some of the performance data obtained during experimentation with the screw heater. During the first 80 minutes of the operation shown in Figure 6, full voltage was applied. For an initial 40 minute period, the extrusion rate slowly decreased as the extruder approached and reached thermal equilibrium. Operation was then continued for about 40 more minutes, during which time the extrusion rate, the die pressure, the temperatures, and the power consumption remained constant. The extrusion rate during this equilibrium period was about 195 grams per minute.

After about 80 minutes of operation, the power to the heater was cut off. An immediate and rapid drop in the extrusion rate was observed. Within just a few minutes the extrusion rate fell to about 50 grams per minute and began to level off and approach a second equilibrium position.

At this point an attempt was made to push the extrusion rate back to its original equilibrium position by increasing the temperature of the barrel near the compression zone. To do this, the cooling water was cut off. The barrel temperature at the compression zone then rose, but the effect on the extrusion rate was quite small, as the curve in Figure 6 shows.

To demonstrate that the screw heater was the con-

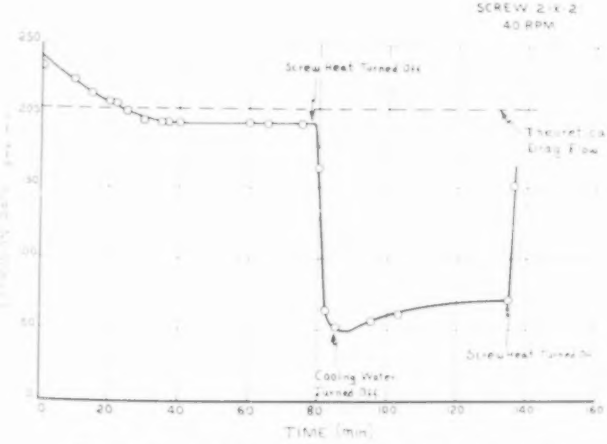


Fig. 6. Effect of Internal Screw Heat on Extrusion Rate.

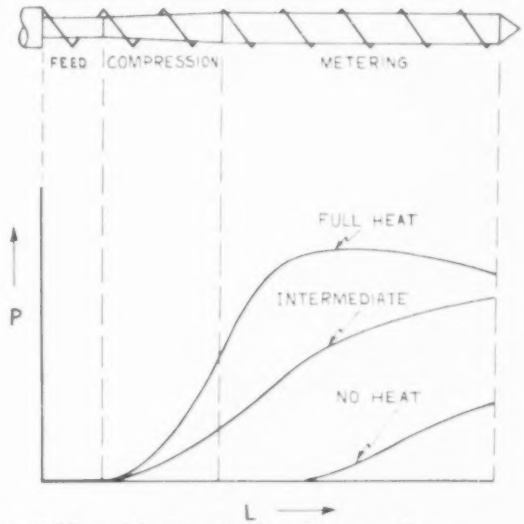


Fig. 7. Effect of Compression Zone Heater on Pressure.

trolling factor, full voltage was again applied. The extrusion rate immediately began to climb. Eventually, it again leveled off at an equilibrium position identical to the original one. Further experiments showed that by applying intermediate heater voltages, intermediate extrusion rates would be obtained.

This very interesting and pronounced effect is caused primarily by the performance of the compression zone of the screw. During these experiments pressure measurements were made at all positions along the length of the barrel and from these measurements pressure profiles were constructed. These profiles throw a great deal of light on the heater effect. First, when no heat is applied to the screw core, the compression zone of the screw operates at a greatly reduced efficiency. At this low efficiency, the capacity of the compression zone to melt and convey polyethylene is much lower than the capacity of the metering zone to pump the molten material. Consequently, the screw channel in the metering zone does not become completely filled with molten plastic, except for a short length close to the end of the screw. Therefore, only a small portion of the metering zone is being utilized to build pressure. This is shown in Figure 7. Under these conditions, insufficient pressure or driving force is generated to push the melt out through the extrusion die, except at a very low rate.

The condition when full voltage is applied to the screw heater is just the opposite. The capacity of the compression zone to melt plastic becomes greater than the pumping capacity of the metering zone and the metering zone actually acts as a restriction to the forward flow of plastic. Consequently, the maximum melt pressure in the screw channel is not at the tip, but occurs somewhere shortly after the compression zone. The pressure decreases gradually from this position toward the die and the pressure flow, in this case, is a forward and not a reverse flow. This is the reason why extrusion rates higher than the theoretical drag flow of the metering zone are sometimes observed. The top curve in Figure 7 shows the shape of the pressure profile that is obtained when the screw is acting in this manner.

The second curve in Figure 7 shows the shape of a pressure profile when the screw heater voltage has been adjusted to some intermediate value so that the capacity of the compression zone just matches the capacity of the metering zone. In this case the pressure build-up occurs gradually over the entire length of the screw. In our experimental program, the screw heater voltage was always adjusted so that the compression zone capacity was equal to, or greater than, the metering zone capacity. Figure 8 shows a typical pressure and temperature profile for one of the extrusion runs.

When the screw heater is turned on, is the increase in capacity of the compression zone caused by increased mechanical working, or does the capacity go up merely because an additional amount of heat is available for transfer into the polyethylene? We feel that it is probably a combination of both. For example, in the run shown in Figure 6, the heater voltage was changed from 0 to 135 causing the melting capacity of the compression zone to increase by about 145 grams per minute (19.2 pounds per hour). Assuming that the polyethylene enters the compression zone at 40°C and leaves at 120°C, approximately 900 watts are required for this capacity increase. The heater is rated at 600 watts at full load. However, not all of the 600 watts can enter the compression zone, as about ⅔ of the heater is located in the metering zone of the screw, as shown in Figure 4. Therefore, we estimate that perhaps 200 watts were available for transfer to the polyethylene in the compression zone. This accounts for only about 25% of the total power required for the observed increase in capacity, so we do not believe that the increased capacity can be explained **only** as an increase in transferred heat.

A reasonable explanation appears to be that the screw heater, at full voltage, transfers enough heat into the compression zone to melt a layer of polyethylene next to the root of the screw, which creates a fluid layer and causes the major part of the polyethylene mass to "slip" easily on the root of the screw. This will substantially increase the pumping capacity and pressure which this section can generate and the material will be pushed forward by the flights with vigor and force. Thus, intense mechanical working occurs because the polyethylene is being forced into a channel of continually decreasing depth.

This analysis really tells us that the design of the compression zone in our experimental screws is not too good, as it is necessary to resort to somewhat drastic means to bring its capacity up to the capacity of the metering zone. The ideal compression zone should work efficiently without internal screw heat. We believe that the compression zone could be improved by making the compression take place in a more gradual manner and by decreasing the helix angle of the screw. We have now designed a new screw along these lines and will shortly begin an evaluation of it.

B. Adiabatic Performance:

Let us now examine the performance of the three screws. The performance data have been summarized in Table V. Extrusion rate, temperature, power, and pressure data were obtained for each of the screws at two different speeds, 70 rpm and 150 rpm. Since the effect of die resistance is most pronounced with the deep flighted screw, all six extrusion dies were used with screw 2-X-1, with screw 2-X-2 dies 2, 3, and 4 were used, while with screw 2-X-3 dies 3 and 4 were used. In addition, the very smallest dies would have generated excessive pressures if they had been used with the shallow flight screw.

It is convenient to plot the performance data on an extrusion rate versus temperature rise diagram. Three diagrams, one for each of the screws, have been prepared and are shown in Figure 9. These diagrams show that the range of extrusion rates and temperatures obtainable with screw 2-X-1 is extremely broad, while the shallower

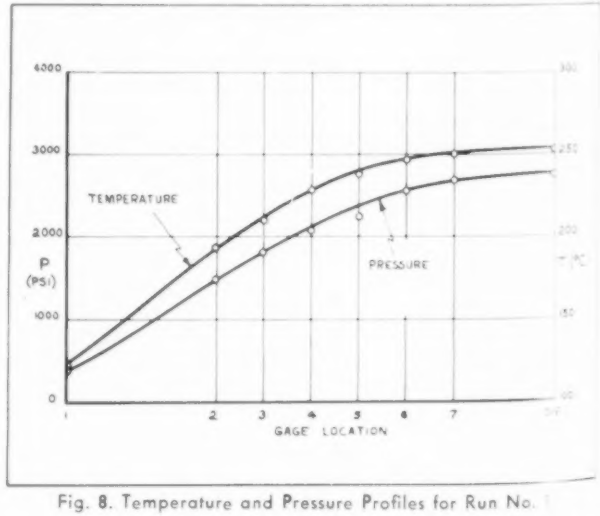


Fig. 8. Temperature and Pressure Profiles for Run No. 1

slight screws have much narrower operating ranges.

It is interesting to compare the actual extruder performance with the theoretical adiabatic melt extrusion performance calculated for these screws. The method of calculation is briefly outlined below.

The first step is to calculate the values of the screw constants α, β, γ, and ε. These constants are calculated from the equations presented in Table I and their values are listed in Table VI.

Certain physical properties of the polyethylene must now be specified. The specific heat of molten polyethylene is roughly 0.5 cal gram^{-1}C. Converting this to the system of units used in the calculations we have

$$C = 300 \text{ in-lbs in}^{-3}\text{C}.$$

Next, the temperature coefficient of viscosity must be specified. The effect of temperature on viscosity for "Alathon" resins has been established approximately from melt viscosity determinations at various temperatures in a piston type rheometer. An average value for the constant, which we have used in the calculations, is $\eta = 0.025\ ^{\circ}\text{K}^{-1}$.

The length of the metering section (12 inches) was selected as the effective screw length (L) which gives 24 inches of helical channel (1).

It is next necessary to select an entering melt viscosity (μ_{te}) to use in the calculations. This selection is rather arbitrary, and we have tried to pick a value that would correspond to the actual melt viscosity at the beginning of the metering section. We used a value of 0.20 lbs-sec in^{-2}.

TABLE VI

Calculated Screw Constants

	Screw 2-X-1	Screw 2-X-2	Screw 2-X-3
α	0.730	0.407	0.235
β x 10^{3}	366	44.3	8.60
γ x 10^{3}	28	6.3	1.32
ε	1370	2590	4480
M x 10^{3}	22.8	43.2	74.8

Having made these decisions it is now possible to calculate the values of the parameter M. Knowing M, the values of $(\beta + \gamma \text{ K } 1)$ and α MN1 are calculated for each operating point. Next values of the parameter R are obtained from the graph in Figure 2 or are calculated from the equation shown in Table II. Once R has been established, the extrusion rate, temperature, and pressure are easily calculated from the equations in Table II.

Plots of the calculated theoretical performance data are shown in Figure 10. Qualitatively speaking, the performance diagrams calculated from the theoretical equations are very similar to the diagrams obtained experimentally. Screw 2-X-1 covers a very broad operating range and a small increase in die resistance has a big effect on the output and temperature rise. For example, at 150 rpm screw speed, the theoretical extrusion rate with die

Summary Data Sheet

TABLE V

Run No.	Screw	Die	N (rps)	Q (in^3/sec)	T(d) (°C)	P(d) (psi)	Input Power Z (Watts)	Input Power q(i) (Watts)	Output Power ΔH (Watts)	Output Power q(w) (Watts)	Output Power q(l) (Watts)	η (%)	Economy (lbs/HP-hr)
1	2-X-1	1	1.17	.095	253	2750	1590	470	920	400	740	77	4.5
2	2-X-1	2	1.17	.155	203	2600	1970	130	1290	370	440	94	5.9
3	2-X-1	3	1.17	.290	159	2040	2620	190	1990	360	460	93	8.3
4	2-X-1	4	1.17	.343	145	1470	2690	240	2200	310	420	92	9.5
5	2-X-1	5	1.17	.495	119	1200	3240	190	2800	340	290	94	11.4
6	2-X-1	6	1.17	.593	107	500	3340	190	2480	0	1050	95	13.2
7	2-X-1	1	2.50	.215	276	3170	3750	130	2130	590	1160	97	4.3
8	2-X-1	2	2.50	.390	228	2950	3990	310	3520	610	170	93	7.3
9	2-X-1	3	2.50	.619	185	2170	5410	70	4710	380	390	99	8.5
10	2-X-1	4	2.50	.770	155	1760	5620	240	5230	520	110	96	10.2
11	2-X-1	5	2.50	.951	128	1400	6560	190	5550	460	740	97	10.8
12	2-X-1	6	2.50	1.28	112	600	7100	190	6200	0	1090	97	13.5
13	2-X-2	2	1.17	.253	195	3200	2700	240	2040	470	430	92	7.0
14	2-X-2	3	1.17	.362	180	1900	2790	480	2750	480	40	85	9.7
15	2-X-2	4	1.17	.410	170	1250	3000	620	2940	350	330	83	10.2
16	2-X-2	2	2.50	.575	225	3500	5510	480	5100	550	340	92	7.8
17	2-X-2	3	2.50	.722	197	2100	5950	480	5800	560	70	92	9.1
18	2-X-2	4	2.50	.795	185	1450	6340	620	6030	490	440	91	9.4
19	2-X-3	3	1.17	.191	203	1300	2220	240	1570	350	540	90	6.4
20	2-X-3	4	1.17	.218	199	780	2270	360	1740	230	660	86	7.2
21	2-X-3	3	2.50	.433	245	1320	4560	430	4030	450	510	92	7.1
22	2-X-3	4	2.50	.466	235	800	4200	560	4180	390	190	88	8.3
23	2-X-3	3	1.17	.210	248	1000	1820	1350	1970	310	890	57	8.6
24	2-X-3	4	1.17	.234	240	600	2200	1130	2100	660	570	66	7.9
25	2-X-3	3	2.50	.438	264	1200	4610	1100	4200	910	600	81	7.1
26	2-X-3	4	2.50	.460	260	650	4550	1150	4320	820	560	80	7.9

Fig. 9. Adiabatic Performance Diagrams.

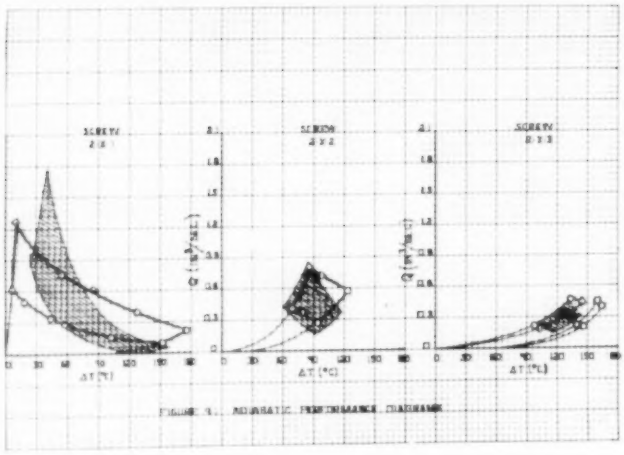
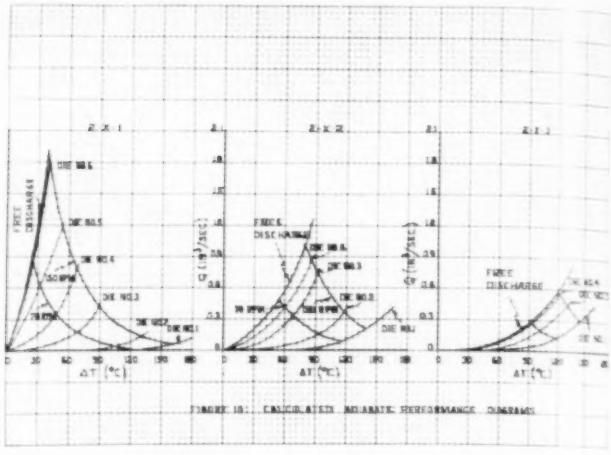


Fig. 10. Calculated Adiabatic Performance Diagrams.



No. 6 (low resistance) is 1.75 in³/sec, while with die No. 1 (high resistance) the extrusion rate is only 0.055 in³/sec. In other words, dies of high flow resistance greatly increase the back flow in screw 2-X-1 and cause the extrusion rate to drop sharply. Screw 2-X-3 lies at the other extreme. It covers a very narrow operating range and changes in die resistance have little effect on either the extrusion rate or the temperature rise. As expected, screw 2-X-2 occupies an intermediate position.

Returning to Figure 9, a quantitative comparison between the calculated and observed performance can be made. The diagrams in Figure 9 have superimposed on them an outline of the theoretical performance. It is immediately noticeable that for screw 2-X-1, the peak extrusion rate is considerably reduced. At 150 rpm and with die No. 6, the observed extrusion rate is 1.28 in³/sec compared with the theoretical extrusion rate of 1.75 in³/sec. The observed temperature rise is 12°C compared with the theoretical rise of 43°C. We believe that heat conduction through the metal of the barrel is the primary cause of this deviation. The large mass of metal in the extruder barrel offers a path of very low resistance for heat conduction along its length toward the relatively cool hopper section, while for truly adiabatic operation, the barrel would have to be a perfect insulator. Consequently, in operation, the temperature profile along the barrel is much flatter than the adiabatic theory predicts. In other words, heat is taken from the front and conducted to the rear by the barrel, and the effective viscosity at the beginning of the metering zone is considerably lowered.

Consider now the high pressure part of the performance diagram. Here the observed extrusion rates are higher than the calculated. The heat conduction effect is, of course, still operating, but we believe that it is overshadowed by another effect. This is the non-Newtonian flow effect. The adiabatic theory was derived on the assumption that the flow behavior was Newtonian. For Newtonian flow through a die, the flow rate, at any given temperature, is directly proportional to the die pressure. In the case of non-Newtonian flow, however, the flow rate through the die is proportional to the pressure raised to some power greater than one. For polyethylene, the exponent is about 2.2. Therefore, for any given temperature and pressure, more of a non-Newtonian material will get through the die than will a Newtonian material. For dies of high flow restriction, where high pressures are generated, this effect becomes important, as the die is not as effective a restriction as the calculations indicate. Consequently, the extrusion flow rates are correspondingly higher.

These same effects are noticeable when the observed and calculated performance of the other two screws are compared, although, since the operating range is much narrower, the magnitude of the deviation is not as great.

Further experiments were carried out with screw 2-X-3 to investigate the effect of increased barrel temperature. One set of runs was made applying voltages in the range of 10-30 to the barrel heaters. A second set of runs was also made using an applied voltage of 85. As the diagram in Figure 9 shows, the higher barrel temperatures caused the extrusion temperature to rise, although it had a small effect on the extrusion rate. The change in performance produced by the different barrel temperatures illustrates how heat transfer can extend the operating ranges of the screws.

The power data for all the runs are summarized in Table V. The input power is listed in columns 1 and 2, while the output power items are listed in columns 3, 4, and 5. Column 5 lists the heat losses from the extruder from all sources except the cooling water stream, which is listed separately in column 4. Heat losses were calculated by subtracting the sum of columns 3 and 4 from the sum of columns 1 and 2.

Column 6 lists the percentages of the total power applied to the system by mechanical working. In runs 1 through 22, the average runs higher than 90%. For the last 4 runs, made with the higher barrel heater temperature, the average is about 70%.

Another index to extruder performance is the so-called power economy, expressed as pounds extruded per horse power hour of mechanical energy expended. These figures are listed in column 7.

In summarizing the performance characteristics of the three screws, it is interesting to note how drastically the characteristic of the very shallow screw differs from the deep one. The range of throughput and temperature conditions which can be covered by the shallow screw without generating excessive pressures is obviously much smaller. It is also evident that its principal advantage lies in extrusions where very high discharge temperatures are needed.

On the other hand, it has the obvious disadvantage that the range of extrusion conditions which can be covered by varying the back pressure is extremely small. All of the extrusion conditions covered by the 0.030" deep screw can also be reached by the 0.120" deep screw

(please turn to page 42)

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AUSTRALIA

AUSTRALIAN PLASTICS

Vol. 8, No. 96, July 1953

Abstracter: Albert Lighthody

EXPANDED PLASTICS (p 6-14) by G. W. Benkendorff

An excellent article covering all of the types of expanded plastics. Each type is carefully described and its principal uses shown. Specific instructions on the methods of producing foams are given for the most important commercial types. Details on the use of the organic foaming agents also give completness to this article.

CHEMICALS BASED ON SUGAR (p 11-16), C. S. R. Chemicals Ltd recently opened a new plant at Rhodes.

A survey of their activities in Australia with photos gives an idea of the growing chemical industry in Australia.

PLASTICS NEWS LETTER (PIA)

Vol. 3, No. 6, August 1953

SHELL MOLDING (p 1-3)

A complete description of the foundry practice using the resin-sand mixture known as shell molding. Only experimental units are in operation in Australia.

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PLASTICS NEWS LETTER (PIA)

Vol. 3, No. 7, September 1953

PREFORMING MOLDING POWDERS (p 1-3), by W. A. E. Robertson

The construction and operation of a single action tabletting press is described. Some of the difficulties and means of overcoming them are discussed.

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FRANCE

INDUSTRIES DES PLASTIQUES MODERNES

Vol. 5, No. 10, December 1953

Abstracter: Hans Mayer

IMPROVEMENT OF AN ELECTRICAL DEVICE

The construction of a multiple position tumbler switch has been greatly improved and the size of the device has been substantially reduced by the intelligent use of molded nylon parts.

MARKET AND MANUFACTURING OF LARGE INJECTION MOLDED PARTS — Jacques Combette

In this second installment the author discusses typical pitfalls in the molding of large injection molded pieces and discusses the features which need to be considered in setting a just sales price for such parts.

FURFURAL RESINS—E. A. Reineck

The story of the development of phenol-furfural compounds is traced from their introduction by Novotny to their latest role as part of phenolic compounds with special flow qualities as needed for the molding of television cabinets. All other applications of furfural in the field of synthetic resins are enumerated as well.

LIGHT AND ADVERTISING

A description of the Rodalux letter set. These letters consist of a holder, a filter and the letter itself, imprinted on a film. The unit is shaped and designed as to fit a fluorescent light tube in such a way that any message can be formed by simply slipping the letters in proper rotation on the tube. The letters cover one half of the tube only, while the other half stays fully exposed. The tube can therefore give the desired message while dispensing light at the same time.

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GERMANY

KUNSTSTOFFE

Vol. 43, No. 12, December 1953

PETROLEUM CHEMISTRY — ITS SIGNIFICANCE FOR THE PRODUCTION OF PLASTICS RAW MATERIALS, by Dr. Hans Sonksen

The birth of Petroleum Chemistry in U.S.A. in connection with the utilisation of refinery waste gases and natural gas is described, followed by an enumeration of its raw material bases. This is accompanied by a description of the more important of converting natural gas- and petroleum hydrocarbons into chemical raw materials. Finally, the synthesis of plastics from petroleum chemicals and the development of plastics production based on petroleum products in various countries are discussed in more detail. It is pointed out that especially the utilisation of hydrogenation waste gases in Germany runs parallel to petroleum chemistry.

ACRYLO-NITRILE AS A CO-MONOMER IN HARD ACRYLIC PLASTICS, by Dr. Klaus Tessmar

Acrylo-nitrile occupies a special position among polymerisable compounds with regard to its chemical and physical properties because of its nitrile group. It is therefore of particular interest as a co-monomer.

This is the first communication about research into copolymers of acrylo-nitrile with acrylate and methacrylate compounds. Forecasts and results are discussed. Here is new proof for the development of "tailor-made" plastics: the results of this research follow the predictions and they show prospects of remarkable practical importance.

POLYTHENE, by Henry Coverdale Raine

The paper illustrates the early development of polythene and deals at the same time with the present situation and prospects for the future. Modern opinions regarding structural characteristics in relation to properties are discussed; the manner in which these properties define and influence various applications is considered.

Kunststoffe (continued)

NEWS FROM THE AMERICAN PLASTICS INDUSTRY, by Dr.-Ing. Karl Mienes

The tendency to achieve ever higher productivity is typical for the American Plastics Industry. Through saving in expenses it tries to reduce costs and to increase turn-over. The significance of the various materials, methods of processing and applications are described.

THE ECONOMICS OF WORKS SIZE IN THE PLASTICS INDUSTRY, by Gerhard Matulat

The choice of the right size of a plant is a problem in every industry. Plastics have been and are developing very fast and new materials with improved properties are continually being produced; therefore, when the plastics economist is determining the economic size of units or planning investments, extensions or modernization of existing units, he is faced with considerations which in other industries are not required at all or not to the same extent.

MARKET RESEARCH IN THE PLASTICS FIELD, by Prof. Dr. Wilhelm Vershofen

Market research in general seeks to investigate the state of economy. Knowledge gained from such research is of interest to every branch of industry. Beyond that we have market research for a particular branch which is best carried out by its own organization. Observations made by individual firms often provide valuable pointers to sales opportunities.

PVC-INSULATED CABLES FOR OPERATIONAL TENSIONS OF MORE THAN 1 KV, by Dr. Wilhelm Birnthaler

The break-down voltage of plasticised PVC is investigated and the field strength permissible for individual conductors estimated. It is found that purely electrical break-down changes to heat break-down at 45 C. Break-down behaviour can be explained by means of the other electrical properties. Finally experiences with cables which have been in use for some time are reported.

PLASTICS AS CONSTRUCTIONAL MATERIALS, by Dr.-Ing. C. M. Freiherr von Meysenbug

It is shown thsat the designer's demand for data cannot refer solely to the characteristics of the material; this applies for plastics as much as for other materials. A design is mainly successful, if it is appropriate to the material and to the stresses to which it will be exposed.

The experience of the last 50 years in the steel field can be transferred—with due allowances—into the plastics field. A short introduction into the conceptions of shape retention and impact effect is followed by some practical examples.

EXTRUDERS, by Obering. Hans Beck

The present state of theoretical knowledge is discussed. Ten conditions are enumerated which practice puts to extruders. General problems are posed and an investigation is carried out as to how near practical designs have come to solving these problems. The performance of an extruder within circumscribed limits can be defined regarding quantity and quality. The formation of a technical committee is recommended to further the development of extruders.

COMPARSION OF WORKING METHODS, by Dr.-Ing. Klaus Stoeckhert

The choice of the correct working method is as important in the Plastics Industry as the choice of the right material. Four examples show that the usual division into thermosetting and thermoplastic materials, or into groups differentiated by their chemical constitution does not give a clear indication of the correct working method.

Grouping according to other considerations, such as type of raw material and application of the final product, affords clear indications as to the method of processing to be selected in individual instances.

THE PRIMING OF THERMOPLASTICS, by Dr.-Ing. Walther Kuhn

A short description of the most important printing processes is followed by a description of the machines which can be used for printing on polystyrene, PVC and polythene.

PRACTICAL EXPERIENCES IN THE METALLIZING OF PLASTICS ARTICLES, by Dr. L. Hiesinger

High vacuum technique has become important to the plastics processor through the process of vacuum deposition. If the plastics material and the method of fabrication are suitably related to the metal deposit, articles of high user value are often obtained.

THE TECHNIQUE OF INJECTION MOLDING THERMOPLASTICS, by Ing. Hans Volland

The production of injection-molded articles, especially with low stresses and high shape retentivity, demands sound knowledge of injection molding technique. Correct processing and design appropriate to the material are the prerequisites for successful application. Practical experiences are reported which should be useful to the user of injection-molding materials as well as to the mold designer.

TRANSFER MOLDING TOOLS FOR THERMOSETTING RESINS, by Obering. W. Bucksch

The advantages and disadvantages of transfer molding are compared, followed by a survey of the most important designs of transfer molds. The characteristics of various types of molds are illustrated by means of complete molds. The article concludes with a description of the fastenings common to all types of tools.

POLYAMIDES IN ENGINEERING, by Dipl.-Ing. H. Zickel

Super - polyamides possess such toughness, wear-resistance and vibration-damping properties that they are used, wherever sliding friction occurs and noiseless running is required. Their very low coefficient of friction, whether they are used dry or with a lubricant, stamps them an ideal material for bearings and gear-wheels. They are supplied in rod form for the machining of parts and as complete injection-molded parts, where larger numbers are demanded. Machining is similar to that of light alloys.

FLAME - SPRAYING OF PLASTICS AND RELATED METHODS, by Dipl.-Ing. E. Gemmer

Flame-spraying and the various powder sinter processes are described with the emphasis on practical application. Purely chemical questions and the very wide fields of application are touched upon. Apparatus, methods of working, materials to be sprayed and plastics which can be sprayed are listed. The related methods of "dipping," "rolling," "powdering" and "cyclone-sintering" are described; advantages and disadvantages, and special fields of application are mentioned.

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DER PLASTVERARBEITER

Vol. 4, No. 7, July 1953

Abstracter: Ernest C. Bernhardt

DEVELOPMENT OF RATIONALIZED MIXING DEVICES by G. Reimann (page 195)

Review of mechanism of mixing and homogenizing devices for powders, and viscous materials. A multi-type "SOHN" mixer is discussed and its flow pattern and design are described.

Vol. 4, No. 10, October 1953

NEW MATERIALS FOR THE CONSTRUCTION OF MODELS FOR PHOTOELASTIC STUDIES by H. Albrecht (page 294)

The development of a hard (EGV-WAL type) and a rubber like polyester resin which can be fabricated

by casting methods is reported. These specific materials for photoelastic studies have low creep, and can be fabricated relatively free of surface stresses.

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Great Britain

PLASTICS

October 1953

Abstracter: A. T. Rexer

P.V.C. PRODUCTION IN WALES— (pp 336-339)

A four page article with illustrations describes the production of p.v.c. at a plant in South Wales.

PLASTICS IN THE SERVICE OF MAN (pp 340-342)

Three pages of illustrations continue the description of high-quality units used in the field of advertising.

DESIGN TRENDS AT THE RADIO SHOW (pp 344-346)

Three pages with illustrations describe the latest commercial productions of the radio and television industries.

THE FARNBOROUGH AIR SHOW (pp 347-349)

Three pages with illustrations show the important contributions which plastics have made in the aircraft industry.

PLASTICS IN AIRCRAFT AND GUIDED MISSILE STRUCTURES by **Wm. E. Braham** (pp 350-352)

A three page article gives some details of the problems and advantages of plastics in modern aircraft construction. Property comparison of plastics and metals at room and elevated temperatures are given in tabular form; included in the table are different types of fiberglas polyester resins, aluminum alclad, stainless steel, and a titanium alloy.

IMPROVING THE QUALITY AND EFFICIENCY OF PLASTICS MOLDING by W. M. Halliday (pp 362-367)

The fourth article on the above subject discusses the recommendations numbered 13 and 14 of the Anglo-American Productivity Team. In particular, accurate control, flow testing, the use of pellets, and high-frequency preheating are covered.

PLASTICS Nov. 1953

PLASTICS IN PREFABRICATED BUILDINGS by J. B. Singer (pp 371-374)

A well illustrated article describes some of the newly developed types of plastic components which are being used in prefabricated buildings. Most attention is paid to panelling and glazing.

PLASTICS IN THE SERVICE OF MAN (pp 376-379)

A pictorial display of high-quality units molded or otherwise fabricated in Great Britain for use as electrical household appliances.

THE RATE OF STRAIN FACTOR IN RELATION TO THE IMPACT STRENGTH PROPERTIES OF PLASTICS by R. N. Howard (pp 382-386)

This article discusses the rate of strain effects in relation to the energy absorption by plastics with particular attention to the simpler types of test pieces. With harder or more glassy type of material, the main factors are those of inertia and of the change in fracture strength with the time of the experiment. With materials showing high elasticity, the energy absorption is much higher and depends mainly on whether or not the highly elastic deformation can occur under conditions of the test. A particular case is considered and it is concluded that at the highest rates of strain the stresses imposed are such that the rate of fracture overtakes the rate of strain. A bibliography is included.

COPOLYMERS — Part I by A. E. Lever (pp 395-397)

This article reviews some of the important materials capable of copolymerization. It includes references to extensive technical literature and patents. Butadiene and vinyl chloride are the first groups considered.

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UNITED STATES

Abstracter: Gerald Eisner

NATIONAL BUREAU OF STANDARDS REPORT NO. 4742

Fluorescent Sunlamps In Laboratory Aging Tests For Plastics

This report covers the investigation preparatory to the development of a laboratory accelerated weathering procedure using fluorescent sunlamps. Various charts and tables are included to show the comparison between the laboratory tests with the fluorescent bulb, the laboratory tests with the S-1 bulb and an actual weathering test performed in Washington, D. C. The findings of the investigation showed the following advantages of the fluorescent sunlamp:

(1) It is cheaper.

(2) It can be used for a longer period.

(3) It does not require the use of a special fixture.

(4) The temperature of the test specimens can be controlled more readily because of the low heat output.

(5) Larger areas of material are exposed.

(6) The tested areas are more uniformly radiated and deteriorated.

These results indicated that an improved laboratory aging test method for plastics might be possible.

Northern Indiana Talk Is On Mold Design

James O. Martin

The Northern Indiana Section heard Mr. Wayne Pribble speak on "Mold Design" at the Jan. 25th meeting held in the Ft. Wayne Chamber of Commerce Bldg.

Mr. Pribble is head of the Barrier-Pribble Co. of New Haven, Ind., Consultants in Plastics and is recognized as an outstanding authority on the subject. He gave an interesting presentation of factors affecting mold costs thru design methods, good and bad. A fine group was present.

A drawing was held for the door prize presented by the Barrier-Pribble Co.

The meeting was preceded by an informal dinner at Monchios Grill at 6:15 p.m., meeting at 7:30 p.m.

The Northern Indiana Section extends an open invitation to all members of the Plastics and associated industries to attend. Contact our president Mr. Phil Leonard of Wayne Plastics Co., 2224 Dwenger Ave., Ft. Wayne, Ind., for specific time and place of the next meeting.

Cyanamid Has New Series Of Laminac Polyesters

A new polyester resin, LAMINAC 4111, which provides far greater chemical resistance than any similar-type resin on the market was announced here today by American Cyanamid Company.

LAMINAC 4111 is a low viscosity styrene monomer modified polyester resin and can be promoted and catalyzed for low temperature or atmospheric curing conditions.

LAMINAC 4110 is a low viscosity type resin designed primarily for use in low temperature curing applications. It is not affected by air exposure during its cure and it dries to a completely tack-free surface in times which can be controlled through the percentage of catalyst utilized. Surfaces may be sanded or finished immediately after curing has been completed.

The new resin is particularly applicable where excellent surface cure and resistance to water are required in the end product, such as in the sports boat industry.

SECTION NEWS

Edited by

Stanley Bindman

Jamison Plastic Corp.
71 E. Sunrise Highway
Freeport, New York

"Our World of Color" Presented at South Texas Officers Elected for 1954 Are Announced

W. E. Wiese

Mr. R. B. Rockwood accompanied by Mr. H. A. Voskamp, Jr. of the Marketing Section of the Barrett Division of Allied Chemical & Dye Corporation discussed "Our World of Color" for the benefit of the South Texas Section in January.

The meeting was held in the Blue Room of the Alabama Banquet Building — Houston, Texas, at 7:30 P.M., January 20, 1954.

Mr. Rockwood used color slides and an interesting running commentary to illustrate the importance of color in the average person's every day life. Some excellent Kodachrome views of the Grand Canyon, Miami Beach, and other landscapes and pastoral scenes were demonstrated as a source of inspiration to designers and manufacturers, who are developing new colors for the consumer market.

In general, any new color falls into one of three classifications: forecast, decorator, or current. A forecast color is one that has been newly developed and has not yet been presented to the public. A decorator color is one which is being "test-marketed" through commercial decorators and interior designers in very limited fields. If a sufficient number of persons approve of a decorator color, it then becomes current and available through retailers for general consumer use.

An almost innumerable variety of colors are available in paints, pigments, fabrics, housewares, etc. Some sell successfully, while others become almost impossible to sell after the first three or four years. Others are successful as current colors over a fairly long period and can be reintroduced to the public from time to time. New colors are becoming available all the time because of new chemical combinations or because of new manufacturing techniques.

The House & Garden Magazine conducts a continuous survey of how well certain colors are being accepted by the public. Through the cooperation of hardware and paint stores, interior decorators and many other retail establishments, this information becomes available to interested manufacturers. House & Garden are able to report what colors currently are most popular, and they are able to predict what colors will be in demand next year.

At the end of the program both Mr. Rockwood and Mr. Voskamp answered many questions about the psychological, theoretical, and practical aspects of color as they affect the Plastics Industry.

Our speakers were introduced by Mr. L. C. Williams, Vice-President of the South Texas Section, who acted as Chairman of the meeting in the absence of Mr. R. W. Meyer, President.

The new officers of the South Texas Section for 1954 are:

Mr. R. W. Meyer—President
Mr. L. C. Williams—Vice-President
Mr. W. E. Wiese—Secretary and National Director
Mr. J. T. Pinkston—Treasurer

Directors, including the above, are Messrs. L. D. Blackwell, F. Chalmers, L. B. Connelly, Harlan James W. A. Meath, and Ky Sandow.

Nosco Plastics Plant Is Greatly Expanded

Paul C. Roche

In line with a transaction completed in the summer of 1953, Nosco Plastics has purchased a plant of 225,000 square feet total floor space on a 30 acre plot on the east side of Erie, Pennsylvania. This plant was previously identified as Standard Stoker Division of Read Standard Corporation. Commencing a move approximately the first of November 1953, all Nosco's facilities and personnel were completely removed to the [illegible] location by mid January 1954. Previously Nosco was operating out of two manufacturing plants and one warehouse. Properties previously owned are now for sale, since the new location comprises adequate room for all operations, with provision for expansion.

Nosco looks forward to smoother operation with the new layout, not only because of the more adequate space, but because modern machine layout permits all interplant transportation to be executed by lift truck, shipping out-going merchandise by pallet wherever applicable. Nosco is one of the largest injection molders in the eastern section of the country, operating 28 injection machines total with 60 ounce top machine capacity. This pioneer company serves the commercial molding field with particular emphasis on the appliance industry, as well as occupying a major place in the proprietary field especially on the strength of its standing in the toy industry.

Alan Hutchings Is Vice-President At Stokes

Francis Dougherty, Jr., president F. J. Stokes Machine Company, Philadelphia, Pa., announces the election of Alan A. Hutchings, sales manager of the company, to the newly created position of vice president in charge of sales. In his new post, Mr. Hutchings will have full responsibility for all marketing activities of the company's wide range of products.

Mr. Hutchings joined the Stokes organization in 1940 as a sales engineer, specializing in plastics molding equipment. As Stokes' line of plastics equipment steadily broadened Mr. Hutchings' responsibilities increased and in 1946 he was put in charge of all plastics sales and service. His duties were further extended in 1950 when he was named general sales manager for all Stokes equipment which includes high vacuum equipment, industrial tabletting and powder metal presses, and pharmaceutical manufacturing equipment.

A native of Chicago, Mr. Hutchings was graduated in 1933 from the University of Minnesota with a B.S. in Mechanical Engineering, and in 1935 from the Wharton School of Finance of the University of Pennsylvania, with an M.B.A. degree. Before joining the Stokes sales staff, he was a sales engineer with SKF Industries Inc., Collins & Aikman Corp., and Courier Corp.

Mr. Hutchings and his wife reside at 422 Hartel Ave., Philadelphia, Pa.

Strobino Is Elected Miami Valley Prexy

Martin Kasch

Frank L. Strobino is elected President of Miami Valley Section of Society of Plastics Engineers. He is a resident of Dayton and is employed by the Phenolic Products Section of Chemical Division of General Electric Company, as East Central Sales representative, with offices in Dayton. He has held this position since May 1949. He has had two years training in all phases of plastics with General Electric, two years at Lehigh University and two years at M.I.T.

Announcement of the election was made at the annual Christmas Dance held at Miami Valley Golf Club, December 4th by retiring President Joe Merke. He also announced the following new officers for 1954. Carl Ackerman, Crosley Corp., Cincinnati as Vice President, Robert Wright, Domestic-Gray Co., Dayton, as Secretary and Richard Bice, Formica Co., Cincinnati as Treasurer. Joe Merke thanked all officers and committee men for their cooperation during the past successful year.

Carl Baer's Band played for the dance and numerous prizes were won throughout fellowship handshakes, games and door prize drawings. The ladies were given corsages and plastic sugar and creamer sets were distributed by the courtesy of F & F Mold and Die Works, Inc. Several of the prizes were donated by Formica Co. Mrs. Walter Oelman received an electric coffee maker, and L. J. Fitz-Harris a clock radio for shaking hands with the right person at the right time. Bernard Stupp won an electric coffee maker, and Galen (Bill) Wilson won an electric steam iron as door prizes. On the game prizes, Mrs. Richard Bice won a set of carving knives, an electric clock, and a shaving knife; (Note the Bice's are again). H. J. Kasch, Jr., won an electric clock, Mrs. David Lucid a portable mixer, Mrs. Ralph Fink a tea kettle and Mrs. William Gerdes, a hot and cold server.

Robert Chollar gave a short talk on the background and history of the local organization. The organization was originally formed as the Miami Valley Plastics Engineers in December 1943, under leadership of Henry J. Kasch, Jr. In July of 1945 the group became a section of the National Organization, Society of Plastics Engineers.

A special feature of the evening was the recognition of past Presidents. Placques were presented to nine past presidents dating back to 1944. Walter Oelman, National President of Society of Plastics Engineers, and Joe Merke presented Walter Oelman with his placque.

Past presidents of Miami Valley display recognition placques. Left to right, front row: Henry J. Kasch, Jr. Kurz-Kasch, Inc., (1944); Robert Chollar, N.C.R. Co., (1945); Dave Meeker, Standard Molding Corp., (1946); Bernard Stupp, Hohman Plating Co., (1947). Back row: Galen Wilson, N.C.R. Co., (1948); Walter Oelman, Standard Molding Corp., (1949); Robert Gerdes, Plastic Moldings Corp., (1950); Martin Kasch, Kurz-Kasch, Inc., (1951); Merle Nelson, Plastic Moldings, Corp., (1952); Joe Merke, Plastic Moldings Corp., (1953).

January Meeting Topic Streaking of Molded Parts

The first meeting of 1954, was held January 7th at Eaton Manor in Hamilton, Ohio. After the fried chicken was put away, Frank Strobino, 1954 President, opened the meeting by introducing the guests as follows: Max Grandy of General Electric Jet Engine Plant—Cincinnati, John Reimueller and Wendell Shearer of Buckeye Molding in Miamisburg and H. C. Brown of Detroit.

He also announced the Committee Chairmen for the new year as follows: Martin Kasch — Publicity, Alfred P. Daignault — Membership, Ralph Bachscheider and Lloyd Larrick, Co-chairmen—Fellowship, Jacques Barnhiser — Credentials, Joe Merke — Program — Cincinnati area, Joe Overwein — Program — Dayton area, Walter Oelman — Technical Activities and National Director.

Walter Oelman was called on regarding National Organization. He commented on the membership drive and goal of 5000 members and asked our support. Miami Valley was well represented at the tenth annual conference in Toronto by Walter Oelman, Dick Bice, Joe Overwein, Byron Nelson and Merle Nelson. Jacques Barnhiser won the fellowship prize for the evening, by greeting the mysterious member at the right time. The prize, his dinner free.

The regular question and discussion period brought out some interesting ideas. The first question was, "What is the best way to clean an injection cylinder?" The first answer was "Take it apart," but there were other methods, such as run additional material thru the cylinder which in some cases could be used over. Another answer was to maintain separate cylinders for different materials or colors. Another question was, "How do you determine the shrinkage on phenolics in compression and plunger molding?" There didn't seem to be much of an answer to this, since most agreed it has been a trial and error method for most part. Being a material representative, Frank Strobino was asked to answer the question. He stated there was generally a note on data sheets which read "For comparison only."

The speaker of the evening was then introduced — Mr. Verne Hannaford, Technical Service Engineer of Plastic Technical Service of Dow Chemical Co., Midland, Michigan. His subject, "Silver Streaking or Pearling in Injection Molded Parts." The subject was interesting and presented very well by the speaker. The question and answer discussion which followed showed interest existed throughout the entire group.

The directors, officers, and committee members met at a special directors meeting January 15th to discuss:

1. Program directors reports
2. Incoming and outgoing treasury reports
3. Incoming and outgoing secretarial reports
4. Change Bank location to Cincinnati area
5. Further director meeting — location and timing
6. New membership

New York Section Elects Schwartz President
Panel Program Discusses Engineering Problems

Arthur M. Merrill

Committee chairman appointments for the New York Section for the coming year were announced by Harold H. Schwartz, Empire Brushes, Inc., and newly elected president, as follows: program, (to July 1) Harriman H. Dash, Arma Corp., and (after July 1) Carl W. Virgin, Naugatuck Chemical Division, United States Rubber Co.; membership, Guy Martinelli, Sylvan Plastics, Inc., assisted by Dewey Rainville, Rainville Co., and Alan K. Zimmerman, Monsanto Chemical Co.; house, Arthur L. GeWertz, manufacturers representative, assisted by Seymour Eisenstadt, Dusal Tool & Mold Co.; credentials, George B. Baron, Ideal Plastics Corp.; favors & prizes, Arthur S. Jacobs, Pressman Toy Corp.; employment, Sam Silberkraus, Riverdale Plastics Development Corp.; education, Herbert J. Weber, Rotuba Extruders; and publicity, Arthur M. Merrill, "India Rubber World."

The panel of experts on plastics engineering problems consists of the following: compression molding — Howard S. Dudley, American Cyanamid Co., Nicholas V. Fasano, Washington Molding Co., Inc., and Mr. Silberkraus; injection molding—Saul Blitz, Tico Plastics, Inc., and Irvin I. Rubin, Robinson Plastics Corp.; molds — William Lewi, Dusal Tool & Mold Co., and Bruno E. Wessinger, Wess Plastic Molds, Inc.; materials—Mr. Martinelli, Richard M. Thews, Monsanto Chemical Co., and J. Martyn Voegtlen, Celanese Corp. of America; assembly and finishing — Stanley Bindman, Jamison Plastic Corp.; and vacuum forming, Marvin W. Davis, Vacu-Plast Corp., and Sanford S. Zimmerman, Vacuum Forming Corp.

New members added by the New York Section during January were: Edward V. Clarke, market development dept., Celanese Corp. of America; Robert B. Coombs, sales manager, Steiner Plastics Mfg. Co.; Milton Graff, president, United Plastic Products Corp.; Leopold Hase, research supervisor, Polytechnic Institute of Brooklyn; Robert E. Miles, salesman, Celanese Corp.; Leon R. Noe, Jr., salesman, Celanese Corp.; and Abe Shaffer, toolroom foreman, Arma Plastics.

The Section regretfully announces the death of a member, Victor Zuger, Plastic-Ware, Inc. A letter of condolence and appreciation for Mr. Zuger's services to the Section and the plastics industry has been sent to his widow.

Herbst is 1954 President of Southern California
Program on Plastic Pipe Stresses Specification Need

Austin Herbst

The business portion of the January meeting was devoted to the introduction of our new officers for the 1954 term as follows:

President: Austin H. Herbst, Technical Director, Irvington Varnish and Insulator, Western Division of Minnesota Mining and Manufacturing Company.

Vice-President: Dale McDonald, McDonald Plastics Company

Secretary: Al Ray, Ray Products Company

Treasurer: L. E. Tallman, Dow Chemical Company

Program Chairman: Walter Kadlec, E. I. duPont Company

Three new members elected to the Board of Directors were: Paul A. Erskine, Hess, Goldsmith & Company; Harold Dague, Collins Caldwell and Dague; William Dewar, Flexfirm Products Company.

Our technical speaker was Mr. Robert E. Deshon, Assistant to the Vice-President, General Sales Manager of the Republic Supply Company of California, who spoke on the subject "Plastic Pipe."

One hundred thirteen members and guests heard Mr. Deshon describe the six basic types of plastic pipe presently being made, and the different physical characteristics of each type. The main portion of the talk covered the problems of the plastic pipe industry to (1) the manufacturer or fabricator, (2) the distribution or selling organization, and (3) to the consumer.

In developing these subjects Mr. Deshon suggested specific improvements of the product necessary to help standardize and arrive at dimensional and quality specifications uniformly throughout the industry.

The speaker outlined the market and future potentialities of plastic pipe, and the competition between the various manufactures, the various types of plastic, and the variation in price.

E. C. Bernhardt Transferred

Dr. Ernest C. Bernhardt, formerly a member of the research staff of Du Pont's Polychemicals Department, has been transferred to the department's Sales Service Laboratory at Arlington, N. J. He will be a member of a group studying new methods of processing the Du Pont family engineering polymers.

Dr. Bernhardt joined the company in 1952. He received his bachelor of science in chemical engineering from Purdue University in 1943, his master's in chemical engineering from the University of Delaware in 1947, and the degree of Doctor of Engineering from the Technische Hochschule in Darmstadt, Germany, in 1952.

Cleveland Elects Moslo President of Section

Frank A. Martin

The December meeting was held in the form of a dinner-dance at the Aurora Inn on December 11. One hundred sixty members, wives, and friends attended. James Underwood, our new national secretary, was the guest of honor, permitting many of our members to meet him personally. Door prizes were fine and numerous through the courtesy of the section and suppliers of the industry.

The board of directors elected the following officers for the year 1954. President is Ernest Moslo, of Moslo Machinery. Ernie will also continue to serve as our National Director. Ross Treer of Warner & Swasey was elected vice-president, Paul Zurlinden of Zenith Plastics, treasurer, and Herbert Oliver of Eastman Chemical, secretary.

New directors are Herb Oliver, Wayne Anderson, and Granville Shirley. Mr. Moslo announced the following committee appointments: Program — Vic Blatter, Membership — Wayne Anderson, and Publicity — Frank Martin.

Bamberger Executives

We are pleased to announce that the Board of Directors of A. Bamberger Corp. has elected Mr. Walter E. Hirtz Executive Vice-President and Messrs. Herbert H. Goldmark, Arthur L. Metzger and Matthew T. Staszak, Vice-Presidents.

The same appointments have been made by the Board of Directors of our affiliate, AMERICAN MOLDING POWDER AND CHEMICAL CORP.

A. BAMBERGER CORPORATION reprocesses plastics scrap, while AMERICAN MOLDING POWDER AND CHEMICAL CORP. compounds vinyl thermoplastic materials and manufactures AMPACET Cellulose Acetate and Polystyrene.

Philadelphia Hears Mysteries of Injection Molding Machinery

H. C. Colby, Jr.

Mr. Adolphe J. DeMatteo, Chief Engineer, the Watson-Stillman Company, Division of H. K. Porter Company, Inc. was the speaker at our January 26th meeting. The title of his talk "The Mysteries of Injection Molding Machines" was appropriate only before his talk, not afterwards.

Mr. DeMatteo discussed control circuits for all common types of injection molding machines, covering in detail the full hydraulic type. He explained in detail the mechanics behind a molding cycle. It was amazing to learn all there is behind what appears to be the simple push and pull of an injection press. We may not have learned to be expert repairmen but we certainly have a greater appreciation of the terrific amount of engineering that goes into our injection presses.

The following officers were announced for 1954: President, Harry Darlington, Jr., A. H. Wirz; Vice President, Jim Rex, Plastics Center; Secretary, Ed. Fitzpatrick, F. J. Stokes; Treasurer, Herbert Clark, Bakelite. In addition the following committee Chairmen were announced: Membership Committee and Educational Committee, Jim Rex; House Committee, Ed Derowski, Penn Plastics; Credentials Committee, Al Hutchings, F. J. Stokes; Program Committee, Norman Skow, Synthane; P.P.P. News, George Koch, Oak Engineering; Professional Activities Committee, Past President Charlie Davis, Stokes—Trenton; Publicity Committee, Curt Colby, Naugatuck Chemical, assisted by John Racon, Plastics Center. Adolph Kissileff, Amplex Mfg. and George Koch are Co-Chairmen of the 1955 Convention Committee. Dick Bishop of Foster Grant has consented to continue as our National Director.

We're all looking forward to our next speaker, Frank Reynolds, who will speak on I.B.M.'s various applications for plastics on February 23rd. Another thing we're anticipating is SPEAC—1955. Translation—SPE in Atlantic City—1955. By the time you read this you will have either attended or missed the Toronto conference. To those of you who attended we say we'll try our darndest to do as well. Those of you who missed it, don't miss another. Remember—SPEAC—1955. It's only a year away.

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West New England Installation

In an annual ceremony, the retiring president presents the Western New England charter to the new president. Left to right: Ray Mazur, Ed Childs, George Martin and John Mallory.

Mold Design Is West New England Topic

C. W. Petersen

A large attendance was on hand at the January meeting of the Western New England Section to see the 1954 slate of officers officially installed and to participate in a forum discussion on the subject of mold design.

Eli Greninger of Bryant Electrical Company, speaking for himself and Rene Magnenat of The Waterbury Company, gave a short prepared speech on mold design and then invited questions from the members. A door prize offered to the members asking the best question of the evening went to William Moss of Wico Electric Company who by requesting information about the use of beryllium copper cavities in plastic molds set off a number of similar questions and a lengthy discussion of this subject.

Messrs. Magnenat and Greninger, each with several years experience in the field of mold design, gave their individual answers to almost every question; thereby providing the members with two experienced opinions.

Prior to the discussion on mold design Edmund S. Childs of Monsanto Chemical Company, past president of the WNES, officially yielded his office to George Martin of Noma Lites Inc., by presentation of the Section's Charter. Childs himself was presented a desk pen set by the membership in recognition of the accomplishments of this Section during the past year.

Watson-Stillman Company Appoints Sales Manager

The appointment of H. E. Elliott as Sales Manager, The Watson-Stillman Company, Division of H. K. Porter Company, Inc., Roselle, New Jersey, was announced by A. B. Diss, Vice President and General Manager.

Mr. Elliott has been associated with Watson-Stillman for the past twenty-five years. He has broad sales and engineering experience and was instrumental in developing many lines of Watson-Stillman hydraulic presses and equipment.

R. W. Schreck has been appointed Assistant Sales Manager specializing in Plastics Machinery Sales.

H. E. Elliott

Frictional Properties of Porous Metal Impregnated with Plastic

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IT HAS been shown earlier that any device which will produce a thin film of low shear strength on the surface of a harder substratum will, in general, give a low friction[1]. If the ploughing term is small the friction between the solids is approximately given by $F = As$, where A is the area of intimate contact and s shear strength at the interface. If both A and s are small, the frictional resistance will be low. Thus experiment has shown that if a thin film of indium ($c10^{-5}$ cm thick) is deposited on to the surface of a hard metal, the friction at heavy loads may be as low as $\mu = 0.04$.

A film deposited on the surface may, by repeated sliding, be worn away, but this difficulty can be overcome by impregnating the harder material with the softer one. With a copper lead bearing metal, for example, the lead is dispersed throughout the copper, either as isolated droplets or as a continuous matrix in between the copper crystals. The sliding process itself then extrudes a thin film of lead over the surface of the copper and it is this process which is largely responsible for the low friction and wear[2].

Frictional measurement experiments on various plastics[3] have shown that solid *Teflon* [polytetrafluroethylene (—CF$_2$—CF$_2$)n] gives a very low coefficient of friction when slid against metal surfaces.

It was found that a film of *Teflon* when simply rubbed on to metal surfaces would give a low value of the friction, but the film was worn away. Porous metal was, therefore, impregnated with the plastic. Sintered copper

Table I. Variation of Coefficient of Friction with Temperature

Types of copper	15°C	100°C	200°C	250°C	330°C	*After cooling to 30°C*
Impregnated with Teflon, sintered	·05	·05	·05	·05	c ·12	·05
Sintered, untreated	·24	·24	c 0·7	c 0·8	c 1·2	c 1
Solid	1·3	c 1·3	c 1	c 1	c 1	c 1

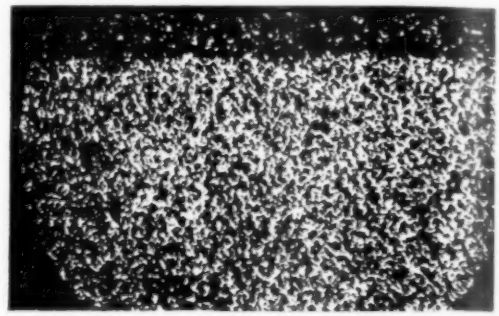

Figure 1. Section of sintered copper impregnated to a depth of c 1 mm with teflon (a) sintered copper (b) impregnated surface layer (magnification × 10, reduced by 2·5 on reproduction.)

(Please turn to page 40)

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Vinyl Paste Resins

(continued from page 15)

...nature of the vinyl tends to cause "melting" of the compound and further impregnation of the fabric. There is also a lubricating action which keeps the temperature development low at the friction point until it is completely worn through. In actual service, the abrasion resistance is said to be 10% more than either rubber or Neoprene.

Aside from spread coating, there is another flooring application of pastes — the print painting of felt base flooring materials. The replacement of the present oleoresinous paints by vinyl organosols is almost certain because the paste fusion step is a matter of minutes compared to days required for the oleoresinous paints to set up. In addition, the resulting coating has greater permanence and flexibility. A proper balance of thinners is required in this application to achieve the desired degree of flowout.

Passing now into dip coating processes, plastisols of low to medium viscosity as well as organosols are widely used for the protection of electroplating racks, fabric gloves, automotive seat springs, electrical parts and iron pipes to mention only a few. The article may be dipped at room temperature or it may be preheated in order to obtain a heavier coating. It is also possible to formulate plastigels or organogels which will dip coat without dripping. A typical compound measured on the Precision Interchemical Rotational Viscometer[5] would have a plastic viscosity of about 1000 cp and a yield value of about 300 dynes. (2) These flow properties are brought about by the incorporation of a small quantity of a gelling agent such as a metallic soap, an organophilic bentonite or a high oil absorption filler. Larger concentrations are used to prepare putty-like pastes, one application of which is as weather-sealants along the drip rails and weld seams of automobiles.

Closely related to dip coating are the slush and rotational molding processes for pastes. While these have been well covered in existing literature, it should be mentioned that large quantities of plastisol are consumed in these fields in the manufacture of toys, mostly children's dolls and doll parts. As many as 150,000 pieces per day have been produced in one plant alone.[6]

Among the new fields of application for vinyl pastes there is one which may well outstrip all others combined in quantity of materials used. These are the expanded vinyl compounds. Closed cell sponge is produced with chemical blowing agents in closed molds under pressure. It is especially serviceable where buoyancy is required, as in floats or life rafts, or as an insulator. On the other hand, its compression set characteristics are inferior to open cell sponge due to distortion and rupture of cell walls under stress. Open cell sponge can be produced with or without blowing agents, its distinctive feature being fusion at atmospheric pressure. There are other means of making vinyl sponge but these are the best known. Perhaps the most promising method of making open cell sponge is that where no blowing agent is used. Plastisol is subjected to an inert gas under pressure and then fused after being released from the pressure chamber.[7] The product is called foam, rather than sponge, because it is derived from a colloidal gas-liquid dispersion. This process, for

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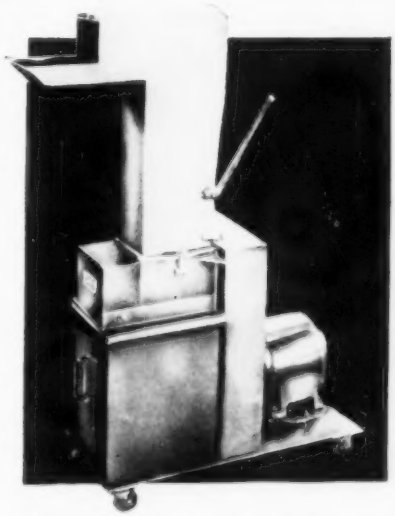

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Vinyl Paste Resins

(continued from page 39)

which patents have been applied by the Elastomer Chemical Co., is shown in a continuous version in Figure 5.

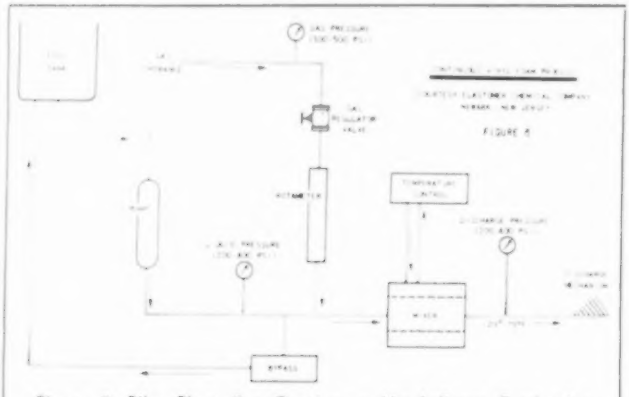

Figure 5. Pilot Plant For Continuous Vinyl Foam Production (Courtesy Elastomer Chemical Co., Newark, New Jersey)

The commercial possiblities of vinyl foam can be assessed from the following considerations. Foam rubber, which is made from latex, has had wide spread acceptance. There were 39 million pounds produced in 1948 and the estimated United States production last year was 185 million pounds.[8] While the raw material costs are comparable, the equipment costs for foam vinyl are claimed to be only a fraction of those for latex along with lower operating costs. For example, the production cycle is shorter, there is less shrinkage, the finished product does not have to be washed, and waste in wet or fused form can be used. The product is flame resistant and has advantage over rubber latex in chemical resistance. It can be cast and fused directly on fabrics and films, both synthetic and natural, thus producing an integral molded object. Moreover, it can be made in the same range of compression resistance as rubber. The applications for foam vinyl are the same as for latex foam—mattresses, furniture, automotive seating and carpet backing.

In a nutshell, this is the story of paste resin dispersions. The known principles have been quickly sketched and the major uses have been indicated along with a few applications of prospective significance. The paste technique is without doubt the most versatile method of utilizing the beneficial properties of vinyl polymers. As such, we can account for its growth and envision its future.

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Frictional Properties of Porous Metal—

(Continued from page 38)

impregnated in this way (*Figure 1*) gave remarkably low values of friction. Some typical results are shown in *Table 1*. Steel was used as the slider and the surfaces were unlubricated.

It will be seen that the treated metal gives a very low friction, $\mu = 0.05$, and this is maintained up to high temperatures. At 250°C the friction is still $\mu = 0.05$. At 330°C, where decomposition of the plastic would occur, the friction begins to rise to $\mu = 0.12$, but on allowing the metal to cool it decreases to $\mu = 0.05$ again. The treated metal shows little sign of surface damage whereas the untreated copper displays marked adhesion, surface damage and wear.

Since the thin plastic film can be fed on to the surface by the sliding process, it is not worn away by repeated sliding: in fact repeated sliding leads to a reduction in the friction.

F. P. Bowden

Laboratory for the Physics and Chemistry of Rubbing Solids
Department of Physical Chemistry
University of Cambridge

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Dear Friends:

I was surprised to write this letter about the time I got to Toronto. Figuring that Editor Jesse Day would not be at [illegible] to receive me I put off writing this till after the Toronto meeting. That Toronto meeting was certainly a big [illegible] Golden Beatty, Malcolm Wilkinson and their multitude of assistants.

As usual, the greatest benefit was from the new perspective gained by hearing about other people's problems and [illegible] it was also helpful to talk about our own problems to anyone willing to listen.

When I came back to the office I had a nice letter from the Navy Department saying they were well pleased [illegible] one of their problems. It involved a silver plated steel molded in a phenolic part. We made metal [illegible] method and they told me that the TOTAL absence of flash inside the mold was very gratifying and that we had [illegible] the previously necessary isolating operation. You as a taxpayer should be glad that we had a go at it.

Cordially Yours,
Wayne Pribble

P.S. To Philadelphia Section: You have a big job to do on the conference next year to keep the ball rolling. You will [illegible] some problems to solve and John LaBelle our new SPE president will need plenty of help. Good luck to you.

Mechanical Properties of Polyethylene

(continued from page 21)

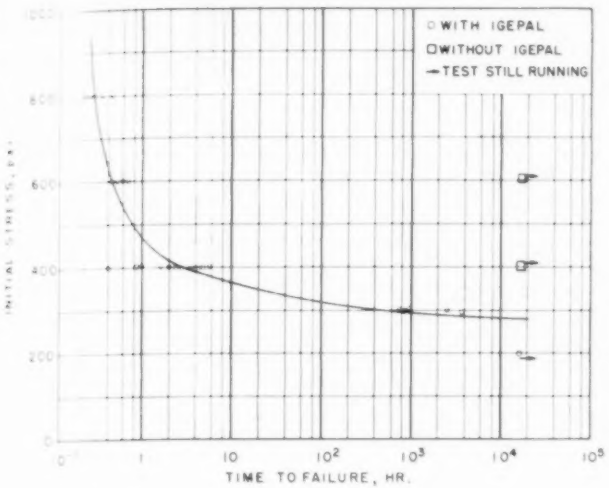

Figure 13. Tensile Stress-Corrosion-Rupture of Polyethylene (Cracking Resistance).

and aluminum sheath from Alpeth cable. Three grades of polyethylene were studied having flow ranges of: (1) 52 to 56, (2) 62 to 68, and (3) 75 to 81. The pipe specimens were coated with Igepal CA Extra and inflated with air. The surface of the tube was, of course under biaxial stress. The air pressure was adjusted to give circumferential (or hoop) stresses from 400 to 1400 psi. and because of the form of the specimens the longitudinal stress was one half the circumferential.

The circumferential (hoop) stress may be computed from the thin-walled tube formula:

$$\text{Stress (psi.)} \quad \frac{pD}{2t}$$

p air pressure, psi.
D average expanded diameter of tube, in. and
t thickness of tube wall, in.

The stress-rupture data are analyzed by plotting time to failure in hours as a function of circumferential (hoop) stress as shown in figure 14. As in most tests of this type, there is considerable scatter in the data but the curves are drawn to represent the lower stress limit below which no failures occurred. With the lowest plasticity range (D52 to D56) polyethylene, no failures occurred in 10,000 hours at stresses less than 430 psi; with D62-D68 resins the asymptotic stress is 610 psi. and with the D-75-81 resins, 1120 psi. (approximately). It is important to note that pipe samples which were not coated with Igepal CA Extra did not fracture although held at stresses corresponding to those used for the coated specimens. Pipe specimens from D52-D56 resins however, showed brittle failure even though not coated with Igepal CA Extra when held at stresses above those reported for the coated specimens. Such failures are to be expected under biaxial stressing as shown by Hopkins, Baker and Howard.[14]

Summary

A number of test methods for describing the mechanical properties of polyethylene have been discussed. The selection of the test method to be used depends primarily upon the application the engineer is considering. It is quite evident that no one method is sufficient to

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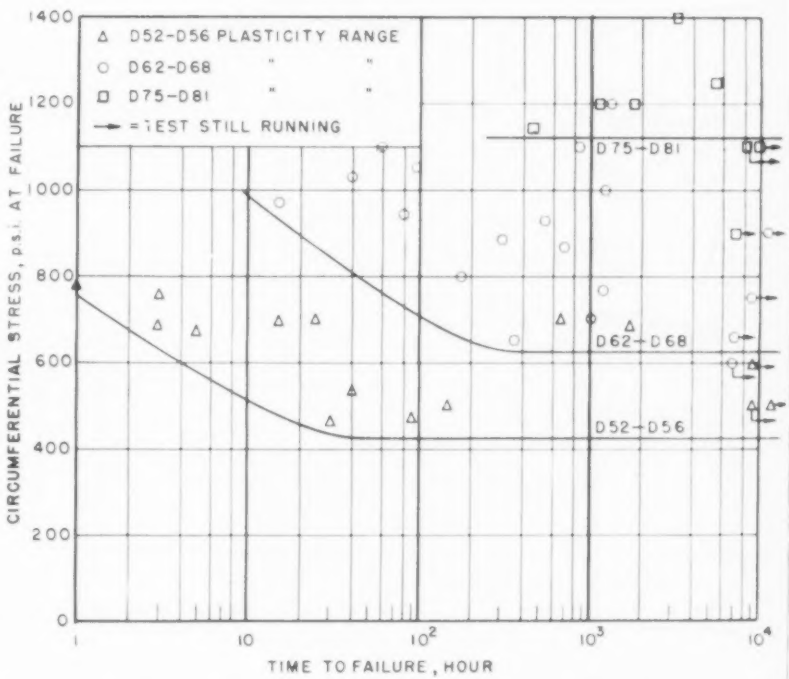

Figure 14. Cracking Resistance of Three Grades of Polyethylene Using Pipe Specimens (Bi-Axial Stresses).

Mechanical Properties of Polyethylene

(continued from page 41)

describe this material any more than is sufficient to describe any material. For this reason, it is wise to avoid conclusions which may be too general. Most of the methods, of course, are designed to point out the limitations of a material. This philosophy is common with most engineers and laboratory technicians who are primarily concerned with the failures that occur and very seldom have time to review the successes.

All of the data show that the tensile strength and final elongation are of limited significance. Short time static tests show that under polyaxial stress conditions, the yield point is the primary criterion for failure. Long time strength tests, the "elastic limit" in short time tests, and data from stress-corrosion-rupture tests qualitatively indicate maximum engineering design stresses of ½ or ¾ of yield point. At present, these criteria apply only to room temperature. Adjustments will have to be made to suit the temperature at which the finished article is used. At present there is no long time stress information at elevated temperature and use of the criteria given above is bound to be hazardous. It should also be pointed out that these criteria provide no factor of safety as used in the customary sense. They do provide a safety factor, however, against the possibility of accidential polyaxial stressing, or accidential contact with damaging chemicals. As in all things, the engineer must combine these data with his own judgement in order to assess the risks he must take. There is no sure way of predicting the 20 or 30 year life. Time alone will tell whether these criteria can be extended to lives of these magnitudes.

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Adiabatic Extrusion of Polyethylene

(continued from page 30)

we were to operate it a bit faster. The 0.120" deep screw is therefore useful for a wider variety of applications.

An over-all look at the graph indicates that considerable advantages might be gained by operating extruders at higher speeds. As screw speed is increased, the slope of the discharge curve for a given die increases. Thus the higher screw speeds will appreciably raise the output of a machine, but will have a diminished effect on stock temperature.

D. **Applications:**

Our experimental work has demonstrated that polyethylene extrusion under near-adiabatic conditions is indeed obtainable in practice. While the correlation between the observed and calculated performance leaves something to be desired (particularly at the extremes of very high and very low die resistances) the adiabatic melt extrusion theory **can** serve as a semi-quantitative guide to the design of extruders for operation with predominantly mechanical power. The experimental work also shows that any combination of a very wide range of extrusion rates and temperatures can be obtained without any transfer of external heat to the plastic, and that the ultimate capacity of the extruder for polyethylene is limited only by the speed and power that the drive can supply. In addition, high extrusion temperatures can be obtained without the necessity of transferring heat from external sources through a high temperature gradient.

Can other plastics also be extruded under near-adiabatic conditions, and if so, will these same advantages be obtained? As we have mentioned before, whether or not a plasticating extruder can be operated adiabatically depends mainly on the solid state properties of the plastic. For polyethylene, for rubber-like materials, or for elastomers the answer is clear. For other plastics, experimentation is necessary before the question can be answered.

Assuming that a plastic **has** the desired solid state properties, will it be possible to obtain adiabatic conditions over a wide range of extrusion rates and temperatures

performance of polyethylene unique? As we have seen, adiabatic control over broad limits depends to a great extent on the screw design and the operating conditions. The greatest range of adiabatic control is possible when the extruder is operated at high speeds. The screw design defines the area of operation. However, good adiabatic control also depends on certain viscous properties of the plastic melt itself. Two properties stand out as being of primary importance:

Viscosity: If the plastic has a high melt viscosity, a large amount of heat can be generated through viscous shearing and a wide range of adiabatic control is possible. Conversely, with materials of very low melt viscosity, it would be difficult, under practical extrusion conditions, to generate much heat mechanically and heat transfer must be relied upon for temperature control.

Viscosity-Temperature Coefficient: A material whose viscosity is reduced only slightly by increasing temperature has a low viscosity-temperature coefficient ("b" value), i.e., a low energy of activation for viscous flow. High extrusion temperatures are more easily reached with plastics of this nature than with plastics whose melt viscosity is greatly reduced by small rises of temperature. Material with the latter behavior is unlikely to reach high temperatures in an extruder because the shear stresses and the mechanical working drop with the viscosity.

The extruder size is another factor which should be considered. In large extruders, the ratio of the area available for heat transfer to the theoretical extrusion rate becomes small, since the heat transfer area is roughly a function of the square of the screw diameter, while the theoretical pumping capacity is a function of the cube of the screw diameter. Thus, full advantage of large extruders will be obtained only when the operation is carried out with heat that is predominantly mechanically generated. We have referred to theoretical output in this discussion because in actual practice, extruder rates are more in proportion to the square of the diameter, indicating that heat transfer is controlling the process.

The adiabatic extrusion theory is not only useful in design applications for new extruders, but can also be used to analyze the performance of existing extruders. By using the equations to construct performance diagrams for existing screws, the potentialities of each screw will be recognized and more advantageous operating conditions may be found.

The application of adiabatic principles need not be confined to those extrusion operations where mechanically generated heat dominates. Even in cases where heat transfer governs the melting of the plastic and may limit the capacity of the extruder, mechanically generated heat may augment heat transfer and extend the operating range of the machine.

One final point concerning the application of the theory should be made. Even in those cases where near-adiabatic operation is possible, it is generally advantageous to design screws for adiabatic operating temperatures less than those actually desired and to use transferred heat to bring the stock to precisely the desired temperature. The final fine control of stock temperature can then be obtained through the use of barrel heaters operated through control instruments.

St. Louis to Visit Corvette Plant March 5

M. Larson

Approximately 200 members and guests of the St. Louis S.P.E. are invited to visit the Chevrolet Plant in St. Louis, Mo. to view the assembly of Chevrolet's new sport car, the Corvette. Mr. E. O. Premo, Assistant Chief Engineer, in charge of production of the Corvette Plastic Body Car, will conduct the tour. Luncheon will be served at the plant, and guests will be invited to ride in production Corvette cars. Mr. Premo will also be the guest speaker at the St. Louis SPE meeting in March.

January Meeting

On Tuesday, January 19, the St. Louis section was very fortunate in having as speaker Mr. William Kosobud, sales engineer of the Chicago office of The Detroit Mold Engineering Co., Detroit, Michigan.

Mr. Kosobud explained to the audience such points as:

Use of air gaps as insulation in molds. Effective temperature zone control within the mold. Dimensional stability of large molds. Proper heat treatment of molds to minimize expansion. Current advance including stabilization. New research that will affect the future of mold design. Background of history of molding.

Approximately sixty members and guests attended the meeting.

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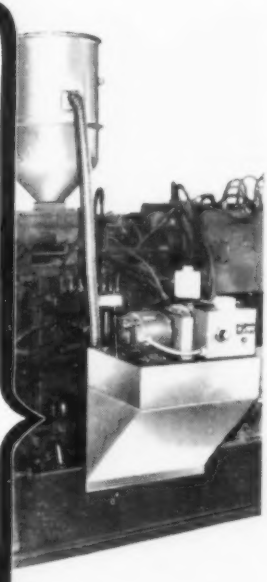

Efficient pre-heating and de-humidifying of material is just one of many jobs done by this timesaving accessory. It speeds production by eliminating handling—because material goes directly to the machine from receiving. No need to load and unload drying ovens. You save floor space, too, because the Hopper-Dryer can be installed easily on standard makes of injection or extrusion machines. Initial cost is less than a drying oven's. Operating cost is low, results are sure.

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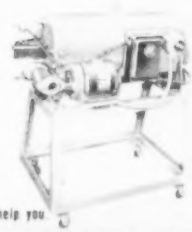

Write today for complete information on how all three of these machines can help you.

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